Chief Scientist & Engineer

Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee

29 September 2023

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Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee
Final Report
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Acknowledgement of the Traditional Owners of the Murray-Darling Basin

The Review acknowledges the strength and struggles of the Traditional Owners, and their Nations, of the Murray-Darling Basin, and their deep and profound connection to their lands and waters.

We recognise the ongoing trauma of fish deaths within their waters and the unwavering dedication to the protection of their Country. We acknowledge the hardships and sacrifices they have made. We respect the inherent connectivity of the river, people, animals and plants, and the deep impact on the Barkandji people when one of these is disturbed.

In the words of a Barkandji Elder Badger Bates:

> *"Our Baaka means everything to us, it is our mother. It is who we are. We take our name from it, Barkandji means people belonging to Baaka. The River is our memory, we walk along it and remember our history and our ancestors by looking at the marks and places."* [1]

We recognise the need for the incorporation of Traditional Owner knowledge and Traditional Ecological Knowledge in natural resource management within the Darling-Baaka and the broader Basin.

We dedicate this report to the Barkandji with gratitude to those who found the strength to share their stories, knowledge and experiences with the Review. We acknowledge their enduring commitment to retell these stories. That knowledge and experience informed – and is reflected throughout – this review.

Information contained in this Review is consistent sswith the views and sensitivities of Indigenous people. There may be words and descriptions that may be culturally sensitive and the report may contain photographs or quotes by Aboriginal people who have passed away. The report also has photographs of totemic symbols that have passed.

The use of 'Barkandji' reflects 'Paakantyi' and 'Barkindji', as the use of 'Baaka' reflects 'Barka'. The use of terms 'Aboriginal', 'First Nations' and 'Indigenous' reflects usage in different communities within the Murray-Darling Basin.

[1] Mr William Brian 'Badger' Bates to the Murray-Darling Basin Royal Commission. The Murray-Darling Basin Royal Commission Report and witness statement.

The Hon Penny Sharpe MLC
Minister for the Environment

The Hon Rose Jackson MLC
Minister for Water

52 Martin Place
SYDNEY NSW 2000

29 September 2023

Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee

Dear Ministers

In April 2023 you asked that I undertake an independent review into the February-March 2023 fish deaths in the Darling-Baaka River at Menindee.

An Executive Summary with Findings and Recommendations from the Review report was submitted on 31 August 2023. Enclosed is the final report from the Review.

As advised in August, our findings and recommendations reflect an understanding of the 2023 event as symptomatic of broader degradation of ecosystem health and consequential long-term pressure on the Darling-Baaka River system. This observation is not new, having been the subject of numerous expert reviews and reports. Data and expert advice provided to this review make clear that without substantive change to our regulatory approach, paired with investment in people, data and infrastructure, there will be further environmental degradation and recurrence of such events. Difficult decisions will need to be made. These are essentially social and not scientific in nature. However, it is hoped that the advice contained in our report will make a positive contribution to the discussions to follow.

I would like to acknowledge the time taken by the local community to share their deep knowledge and experience of the river, lakes and surrounds. Their love and concern for the health of the Darling-Baaka River, and implications for community, are palpable. I am particularly thankful for the generosity and patience of the Barkandji People in sharing their knowledge and insights with the Review, and acknowledge their enduring connection to, and care of, the Darling-Baaka River and all its species. That community knowledge informed – and is reflected throughout – this review.

I acknowledge also initiatives made by agencies in recent years to address many of the issues examined in this Review. Individuals and agencies made valuable submissions and were generous in sharing their expertise and deep knowledge with the Review team.

Finally, I thank the Expert Panel members for their expertise and insights: Professor Robert Vertessy, Professor Lucy Marshall, Professor Lee Baumgartner, Associate Professor Bradley Moggridge, Dr Sarah Mika, Associate Professor Michael Reid and expert advisor (emergency management) Mr David Owens.

H. Durrant-Whyte.

Professor Hugh Durrant-Whyte
NSW Chief Scientist & Engineer

Contents

Glossary

ANZECC	Australian and New Zealand Environment and Conservation Council
ARENA	a national system for supporting the use of aircraft for fire and emergency response
ARENA HP	a national system for supporting the use of heavy plant and equipment for fire and emergency response
Basin Plan	Murray-Darling Basin Plan 2012
CDSC	Capability Development Sub-Committee
CEWH	Commonwealth Environmental Water Holder
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CyHV-3	herpesvirus 3 / carp virus
DO	Dissolved Oxygen
DPE	Department of Planning and Environment
DPE-EHG	Department of Planning and Environment – Environment and Heritage Group
DPE-Water	Department of Planning and Environment – Water
DPI	Department of Primary Industries
DPI-Fisheries	Department of Primary Industries – Fisheries
EM	Emergency Management
EMPLAN	Emergency Management Plan NSW
EOC	Emergency Operations Centre
EOCON	Emergency Operation Controller
EPA	Environment Protection Agency
EWA	Environmental Water Allocation
FRNSW	Fire and Rescue NSW
GL	Gigalitres
HBWG	Hypoxic Blackwater Working Group
IMT	Incident Management Team
kg/ha	kilograms per hectare
kg/hr	kilograms per hour
KHV	Koi Herpesvirus Disease
LEM	Local Emergency Management
LEMC	Local Emergency Management Committee
LEOCON	Local Emergency Operation Controller
LLS	Local Land Services
MDB	Murray Darling Basin
MDBA	Murray Darling Basin Authority
mg/L	milligrams per litre
ML	Megalitre (unit of volume: one million (1×10^6) litres)
ML/day	Megalitres per day

MLD Plan	Water Sharing Plan for the NSW Murray and Lower Darling Regulated Rivers Water Sources 2016
NCCP	National Carp Control Program
NPWS	National Parks and Wildlife Service
NRC	Natural Resources Commission
NSWPF	New South Wales Police Force
OCSE	Office of Chief Scientist & Engineer
PIFA	Public Information Functional Area
PPPR	The prevention, preparedness, response, recovery (PPRR) model
RACC	Regional Algal Coordinating Committee
REOCON	Regional Emergency Operation Controller
RFS	Rural Fire Service
SEED	Sharing and Enabling Environmental Data portal
SEMC	State Emergency Management Committee
SEOCON	State Emergency Operation Controller
SERM Act	*State Emergency and Rescue Management Act 1989 No 165.*
SES	State Emergency Service
SITREP	Situation Report
TEK	Traditional Ecological Knowledge
TN	Total Nitrogen
TP	Total Phosphorous
WSP	Water Sharing Plan

Executive summary

In mid-March 2023 an estimated 20-30 million fish died in the Darling-Baaka River near the town of Menindee, NSW. This event – following prolonged flood, extended drought and previous mass fish deaths – has had a profound impact on both the environment and the local community.

The Office of the Chief Scientist & Engineer (OCSE) has reviewed the causes and contributing factors, environmental conditions, water management and emergency response to this event. Our findings and recommendations reflect an understanding of this event as symptomatic of broader degradation to ecosystem health and consequential long-term risks to the Darling-Baaka River system.

Findings

1. Hypoxia – resulting from low dissolved oxygen in the water column – was the most likely proximate cause of fish death.
2. Low dissolved oxygen in the water column was driven by a confluence of factors, including high biomass (particularly carp and algae), poor water quality, reduced inflows and high temperature. The area around the Menindee Lakes is particularly susceptible to fish deaths events.
3. Mass fish deaths are symptomatic of degradation of the broader river ecosystem over many years. Changes to flow regime and fish passage from water infrastructure and altered water use in the northern Basin are likely key factors in decreasing water quality and the decline of native species.
4. The health and wellbeing of the local community is inherently linked to the health of the river. Consecutive mass fish deaths have had a profound, ongoing community impact: social, cultural, mental health and economic.
5. Explicit environmental protections in existing water management legislation are neither enforced nor reflected in current policy and operations. Water policy and operations focus largely on water volume, not water quality. This failure in policy implementation is the root cause of the decline in the river ecosystem and the consequent fish deaths.
6. Data limitations (e.g. resolution, water quality and biomass) have hindered timely decision making.
7. While limited, observations and monitoring data indicated compromised water quality and potential for fish deaths prior to the March 2023 event. However, the scale of any potential event was underestimated.
8. An initial lack of understanding of emergency management arrangements by key stakeholders hampered a swift response. Lack of clarity around agency responsibilities and funding streams further hindered response and recovery.
9. There is a clear disconnect between agencies involved in ongoing river operations and those responsible for emergency management. Triggers for response are not clearly defined.
10. Communication of ongoing river operations and during the emergency are/were inconsistent, not timely and did not always consider local/regional accessibility. Trusted voices within specific communities and Aboriginal groups were not engaged. Local and Traditional knowledge and experience was rarely used by agencies to inform management actions.
11. The local community feel that their knowledge, insights and experience of the river, lakes and broader environment are not given appropriate consideration in water policy, operations, environmental protection and emergency management.
12. Mitigation of fish deaths currently relies on releasing limited environmental water holdings. This is unsustainable, inconsistent with their purpose, expensive and carries a significant opportunity cost.
13. Further mass fish deaths are likely. Decomposition of dead fish and other biota from March 2023 will likely continue to deplete oxygen and release nutrients (i.e. a feed-forward loop). Reduced flows with a drying climate trend and high spring/summer temperatures exacerbate this risk.
14. Many of the issues identified in this review have been well documented in previous reports. However, many of the recommendations made in those reports have not been implemented. This lack of action represents a clear contributing factor to ongoing system decline and fish deaths.

Recommendations

A lead agency should be clearly tasked with responsibility and oversight for implementation and reporting progress against the following recommendations.

Recommendation 1: Regulatory environmental protections must be enforced

The regulatory framework must be upgraded to include legally enforceable obligations and powers to give effect to environmental protections and whole of catchment ecosystem health, as expressed in the objects of water, environmental and biodiversity legislation. Changes should:

a. draw on scientific, cultural and local community insights and be developed in partnership with these knowledge communities
b. address risks to the Lower Darling-Baaka and its water-dependent ecosystems
c. be informed by an independent review of existing water rights, water accounting systems, exercise of rules and operational parameters, and their impact on riverine catchment health. This includes provisions in Water Sharing Plans to improve water flow across the system
d. be based on much improved real-time data and monitoring of the whole river system.

Recommendation 2: Better decisions require better data

An integrated, open, whole-of-system approach to data collection, analysis and management needs to be established. This is essential to enable timely and transparent decision making and build trust in the community. This water data regime should be based on the following principles:

a. the data must cover the whole of the river system as all parts are connected. The monitoring network needs to be expanded to address key gaps (e.g. sites, resolution, and indicators)
b. the data must minimally cover water flow rates and water quality (including dissolved oxygen), fish and algal biomass, and monitoring cause and effect variables to provide early warning of deteriorating conditions and ecosystem response
c. the data must be open and accessible to all (Findable, Accessible, Interoperable, and Reusable - FAIR https://ardc.edu.au/resource/fair-data/).
d. investment in new sensors and technology platforms (including telemetry), and their maintenance, to provide adequate coverage and early warning
e. development and use of probabilistic models and baseline steps towards a catchment digital twin, drawing on real time data, machine learning algorithms and insights
f. recognition and integration of community observations and Aboriginal Traditional Knowledge as important sources of evidence.

Recommendation 3: Effective emergency management

A local, detailed and effective emergency management framework is required. The current system is dysfunctional and not well understood at the local level.

a. a NSW Mass Fish Death Sub-Plan, under the Emergency Management Plan NSW (EMPLAN) should be developed and implemented as a matter of urgency (including a specific Menindee appendix)
b. a simultaneous assessment of emergency management resources should be undertaken. This includes a review of membership and training; assessment of current prevention and response resourcing, capability and volunteer capacity
c. resources should include development of a communications plan and an educational resource package.

Recommendation 4: Interventions to mitigate against future mass fish deaths

An integrated suite of strategies should be designed and implemented to reduce the risk of further mass fish deaths and restore the health of the broader river ecosystem. These strategies should include improved monitoring, data collection and sharing, and be integrated with other recommendations in this report. The strategies should ensure risks are identified and managed, impacts quantified and adaptive learning implemented. These interventions should at least include:

Immediate term measures (0-12 months) to manage water quality should focus on maintaining dissolved oxygen in the Menindee weir pool. Potential interventions include:

a. modifying the nature of environmental and other water releases (such as pulsing releases) to maximise desired benefits
b. pumping/recirculation infrastructure to enable water release from Pamamaroo outlet without exhausting environmental water holdings
c. investigating the feasibility of oxygenation infrastructure to maintain refugia in designated areas
d. reducing oxygen demand in the Menindee weir pool by reducing biomass - including fish removal (especially carp) and suppression of algal growth
e. applying short-term technical fish passage solutions to create temporary opportunities for fish to progress upstream

Mid-term strategies (1-5 years) include:

a. construction of fishways identified in the NSW Fish Passage Strategy. Priority and resourcing should be given to the construction of effective fishways to maximise fish mobility above the Menindee weir pool.
b. an integrated national invasive fish species management strategy be finalised and resourced. Implementation of the strategy should be accompanied by an information, communication and education plan, informed by local and Aboriginal knowledge, and subject to monitoring and annual reporting of actions, impacts and adaptive management responses.

Long-term strategies (ongoing) include:

a. restoration of flow regimes and connectivity across the catchment
b. water quality – accounting and management of nutrient inflows across the catchment
c. coordinated and systemic ecosystem regeneration strategies, inclusion of Aboriginal people's knowledge, including R&D and scale up of refugia for fish, invertebrate and other species
d. in addition to other performance and impact metrics, the strategy should include monitoring of iconic long-lived animal, plant and invertebrate species recognised for their contribution to river health, including species identified as culturally significant to Indigenous communities.

1. Introduction

The Murray-Darling Basin covers an area of more than one million km² in the southeast of Australia (Figure 1).[2] The Basin includes large areas of NSW and Victoria, the Australian Capital Territory and some of Queensland and South Australia. The northern Basin encompasses the Barwon-Darling River and its tributaries (i.e. intersecting streams, Border Rivers, Gwydir, Namoi and Macquarie). The southern Basin extends south of Menindee Lakes. Most of the rivers flowing into the Basin start as fast-flowing streams in the mountains of the Great Dividing Range, located to the south and east of the Basin.

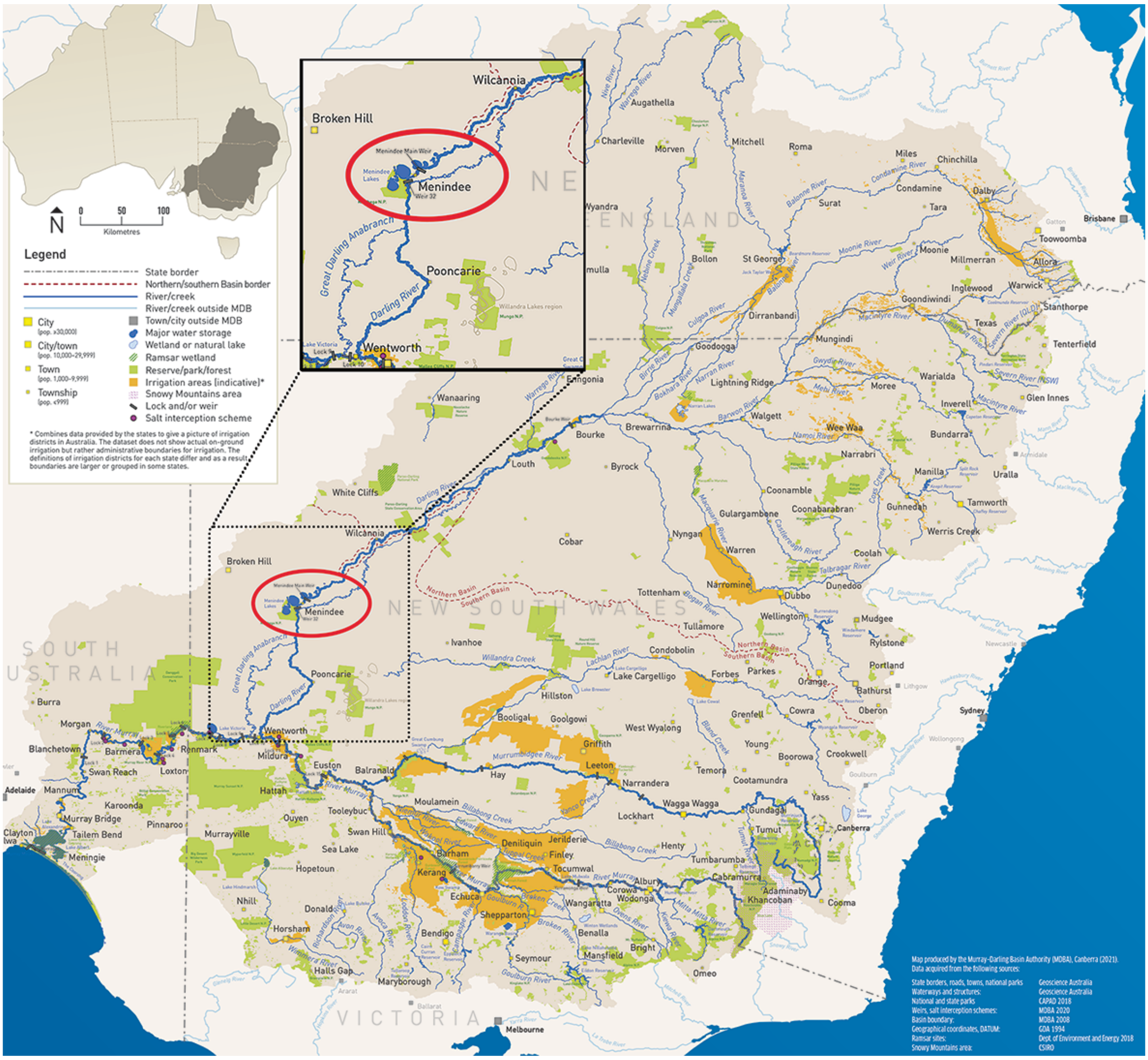

Figure 1. Murray-Darling Basin map, zoomed in on the Menindee lakes system. *Source: Murray Darling Basin Authority (MDBA).*

1.1 The Darling-Baaka and Menindee Lakes system

The Menindee Lakes ('the Lakes') are located on the Darling-Baaka River in south-west NSW, approximately 200 kilometres (500 river km) upstream of the junction with the Murray River at Wentworth. The Lakes lie within the traditional lands of the Barkandji people. These traditional lands

[2] Murray-Darling Basin Authority (nd). Basin Location.

encompass an area of some 19,000km^2 extending from Wilcannia downstream to Wentworth, and the back country around Paroo River and Broken Hill.[3] The indigenous name for the river now known as the Darling is 'Baaka', and the 'Barkandji' people's name acknowledges the people of the Baaka (the river). The native title rights of the Barkandji as the Traditional Owners of the lands and water have been recognised by the Federal Court of Australia.[4] However, water rights remain an important issue to be resolved, particularly water entitlements.

Previously a series of naturally ephemeral shallow wetlands, the Lakes and nearby river were significantly modified during the 1950s and 1960s to provide water storage and supply to Broken Hill and other towns and irrigators along the Lower Darling and Murray rivers.[5] The Menindee-Broken Hill Pipeline has since been decommissioned, and Broken Hill is now supplied via pipeline from the Murray River near Wentworth. The Lakes are now a regulated storage system consisting of four main interconnected lakes (Figures 2 and 3). Lakes Pamamaroo, Menindee and Cawndilla are modified natural depressions, and the fourth, Lake Wetherell, was artificially formed by the construction of the Main Weir and levee. Lakes Pamamaroo and Menindee are connected by an artificial channel via Copi Hollow. The combined surface area of the four main lakes is 457km^2, with a combined storage volume of 1,687,000ML at full supply level and a maximum capacity of 2,284,500ML (based on maximum surcharge level).[6]

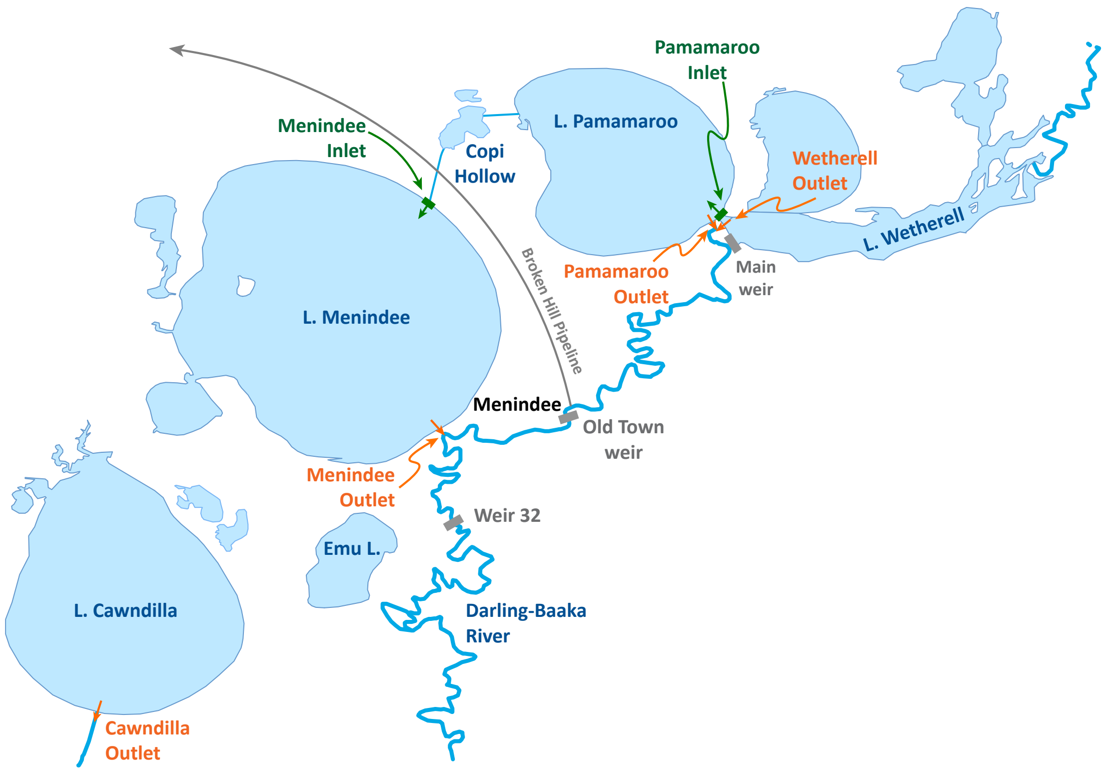

Figure 2. Menindee Lakes system. Key infrastructure regulating storage and distribution of water within four main interconnected lakes. *Source: OCSE.*

[3] The Barwon-Darling upstream of Menindee Lakes spans several nations, including Euahlayi, Barkandji, Murrawarri, Ngemba, Gomeroi/Kamilaroi and Ngiyampaa Aboriginal people. Upstream from Menindee Lakes is recognised as the Barwon-Darling Barwaan-Culliwatta-Baaka. From Menindee Lakes to downstream to Wentworth the land is recognised as the Lower Darling–Baaka and is Barkandji Country.

[4] National Native Title Tribunal (2015). Barkandji Traditional Owners #8 (NC1997/032).

[5] NSW Government (2018). Menindee Lakes Water Saving Project Fact Sheet.

[6] WaterNSW (2023). Menindee Lakes: Facts and History.

The relatively shallow lakes are managed to maximise storage volumes and minimise evaporation while also maintaining the structural integrity of the infrastructure and mitigating damage to the township during time of flood. Lakes Wetherell and Pamamaroo are the preferred water storage lakes, rather than the shallower Menindee and Cawndilla. the usual order of release into the Lower Darling-Baaka River is initially from Lake Menindee, then Pamamaroo and Wetherell. Releases via Cawndilla outlet flow into the Great Darling Anabranch via Tandou Creek.[7]

Construction of the Menindee Lakes Scheme system has significantly altered the flow regime of the Lower Darling-Baaka River. The frequency of freshes (short-duration flow events that submerge the lower parts of the river channel) and bankfull (large enough to fill the river channel with little spill onto the floodplain) flows has reduced, flow seasonality has changed, winter flow variability has reduced and low flows are more persistent since the operation of the scheme commenced in the 1960s.[8,9]

The section of the Lower Darling-Baaka River adjacent to the Lakes (between Weir 32 and Main Weir) is particularly prone to mass fish death events. Hypoxic conditions (in association with both flood and drought) are now a recurring event in this section.[10] River regulation has significantly altered flows and regulating structures represent a significant barrier to fish movement in a part of the Basin considered key for fish recruitment and breeding, and for connecting the northern and southern Basin. Reductions and changes to the pattern of inflows from northern Basin tributaries have likely compounded this impact.

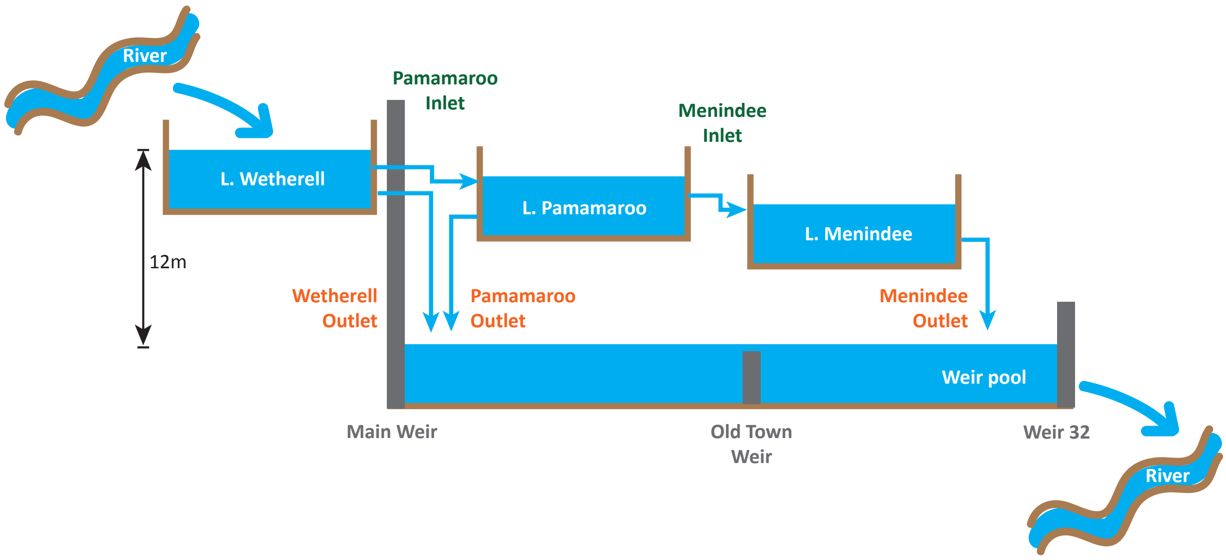

Figure 3. Water flow within the Menindee Lakes system. Cross section (elevation view) showing key infrastructure regulating water flow. *Source: OCSE.*

[7] NSW Government (2018). Menindee Lakes Water Saving Project Fact Sheet.

[8] Green, D., Shaikh, M., Maini, N. et al. (1998). Assessment of Environmental Flow Needs for the Lower Darling River. Report to the Murray Darling Basin Commission by the Department of Land and Water Conservation, Centre for Natural Resources, CNR 98.028.

[9] NSW Department of Primary Industries (2022). Fish and Flows in the Southern Murray-Darling Basin: Developing environmental water requirements for native fish outcomes.

[10] In association with floods, large quantities of organic compounds dissolve into flood water, which is consumed by microbes and leads to a sudden depletion of dissolved oxygen in the water.

1.1.1 Operations and statutory requirements

A range of water, environmental and planning statutes and regulatory instruments apply to the Lakes, rivers and the Basin more broadly. Environmental health, protection and restoration are contained in regulatory objectives.

The Lakes and associated infrastructure are owned by the NSW Government and operated and maintained by WaterNSW for the benefit of NSW, Victoria and South Australia. WaterNSW is required to operate the Lakes and the Lower Darling-Baaka River in accordance with the rules in its works approval,[11] the *Water Sharing Plan (WSP)*[12] *for the NSW Murray and Lower Darling (MLD) Regulated River Water Sources 2016* and the *Murray Darling Basin (MDB) Agreement*.

The MLD WSP includes environmental and water quality objectives related to maintaining water quality within target ranges for a range of purposes. Examples include supporting water-dependent ecosystems and ecosystem functions, agriculture, domestic and stock use, recreation and suitability for Aboriginal cultural use. The MDB Agreement requires New South Wales (and consequently WaterNSW as the river operator) to maintain storage and associated works in good working order and deliver minimum flows.

The Murray Darling Basin Authority (MDBA) is responsible for sharing water in accordance with the MDB Agreement. The MDBA can call on Menindee Lakes storage to meet downstream demands when the combined Lakes' storage volume exceeds 640GL. When the combined storage falls below 480GL, the MDBA cannot make orders for interstate requirements and the Lakes are under NSW control until capacity rises above 640GL again. At the time of the March 2023 fish deaths, the combined volume in the Lakes exceeded 640GL.

1.2 Fish death events in the Lower Darling-Baaka River

Fish deaths are a sudden mass mortality of fish.[13] They can occur at any time but are more likely during summer or following sudden changes in temperature. Fish deaths have been occurring in this river reach for many years but not at the scale and frequency recently observed decades.[14] A list of recent fish death events can be found on the NSW Department of Primary Industries website.[13]

During a period of drought in December 2018 and January 2019, there were two large-scale fish deaths in the Lower Darling-Baaka River at Menindee:[15]

- December 15, 2018: tens of thousands of dead fish stretching approximately 30km from Main Weir through to a point upstream of Weir 32
- January 6, 2019: hundreds of thousands of dead fish along the same stretch of the river.

In these instances, fish deaths were caused by thermal stratification of the weir pools which created hypoxic conditions. In short, an extended period of very hot weather led to layering of water, with a layer of cooler water with very low dissolved oxygen levels near the bed of the river.[16] A sudden temperature drop caused the water layers to mix, resulting in decreased dissolved oxygen throughout the water

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[11] The Independent Pricing and Regulatory Tribunal (IPART) NSW audits and reports annually on the performance of WaterNSW against its operating licence conditions.

[12] Water sharing plans are statutory instruments under the NSW Water Management Act 2000. They prescribe how water is managed to support sustainable environmental, social, cultural and economic outcomes.

[13] NSW Department of Primary Industries (2023). Fish Kills in NSW.

[14] "Research into Australian newspapers reports of dead fish observed in the MDB includes Bourke (1885, 1903 and 1951) and Wilcannia (1920 and 1929). A consistent theme is very low flows, with reports of 'saline' or 'impure' water, brackish water release (e.g. upstream of Bourke) or deaths following a fresh release of water following a period of stagnation." Source: Hope, J. (2019) Selected historical records of dead fish in The Murray-Darling Basin to 1951 presented at the Australian Archaeological Conference 2019.

[15] NSW Department of Primary Industries (2019). Fish Death Interim Investigation Report: Lower Darling River Fish Death Event, Menindee 2018/19.

[16] Murray-Darling Basin Authority (2023). Menindee Fish Deaths.

column, below the threshold needed to support fish life. For each of these fish death events, the weir pool in which the fish were trapped was bordered downstream by an impenetrable barrier (a weir) and upstream by a dry channel. Ultimately, it was concluded that the rapid transition from favourable conditions to highly adverse ones resulted in such high numbers of fish deaths.[17]

Two further fish deaths events occurred in 2023 following a period of flooding, the second being the worst fish death event recorded in the region:[18]

- February 24-28, 2023: from the Main Weir to Menindee Town. Tens of thousands of dead fish, predominantly bony herring (*Nematalosa erebi*), with smaller numbers of golden perch, Murray cod and carp (*Cyprinus carpio*) all affected.
- March 16-18, 2023: from the Main Weir to the confluence of Menindee Creek. Millions of fish (predominantly bony herring, with smaller numbers of Murray cod, golden perch and carp as shown in Figure 4).

Figure 4: Fish deaths. An estimated 20-30 million dead fish died in the Darling-Baaka River at Menindee. *Source: ABC News (Bill Ormonde).*

DPI Fisheries undertook a preliminary survey of the estimated density of dead fish along the stretch of river near Menindee (Figure 5), however the methodology is being trialled and has not yet been peer

[17] Vertessy, R., Barma, D., Baumgartner, L. et al. (2019). Independent Assessment of the 2018-19 Fish Deaths in the Lower Darling: Final Report.

[18] NSW Department of Primary Industries (2023). Independent Review into the February-March 2023 Fish Deaths in the Darling-Baaka River – DPI Fisheries submission.

reviewed.[19] This survey indicated that the highest density of fish deaths occured in the middle reaches of the weir pool, upstream of Menindee town.

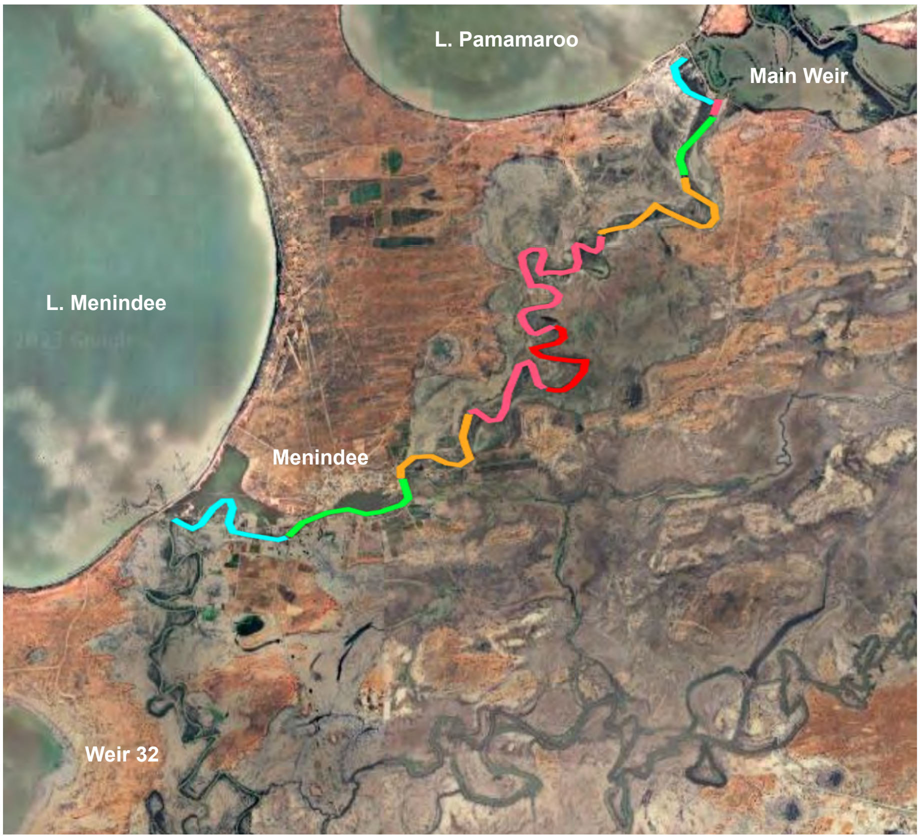

Figure 5: Heat map of relative fish death density in Menindee weir pool following May 2023 sampling. Blue: Low; Green: Low to Medium; Orange: Medium; Pink: High; Red: Very High. *Source: DPI Fisheries.*[20]

The site of the 2023 fish deaths along the Lower Darling-Baaka River is part of the aquatic ecological community in the natural drainage system of the lowland catchment of the river.[21] The listing of this community as endangered in New South Wales indicates it is at risk of becoming extinct unless steps are taken to address key threats to its survival. Importantly, the listing of this endangered ecological

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[19] DPI Fisheries: these are preliminary findings, therefore we recommend that they are not used to establish causal relationships as it is unlikely to be robust enough to accurately establish cause-and-effect connections. Note that the method is subject to review. Therefore, the method is not yet suitable for integration with other established quantitative datasets and the methods may have inadvertent bias, generalisation or limitations that have not been thoroughly identified. If the full review process recommends revisions or refines the methodology, the findings may be revised.

[20] Source: DPI Fisheries, with caveats on use.These are preliminary findings, and DPI Fisheries recommends that they are not used to establish causal relationships. The method is subject to review and therefore, not yet suitable for integration with other established quantitative datasets. The methods may have inadvertent bias, generalisation or limitations that have not been thoroughly identified. If the full (methods) review process recommends revisions or refines the methodology, the findings may be revised. The data and supporting information is provided on the understanding that DPI Fisheries are providing the data to OCSE for the purposes of the Review. The data cannot be used for any other purpose without written consent from DPI Fisheries. DPI Fisheries cannot be held responsible for any use and interpretation of Fisheries data where Fisheries was not provided reasonable opportunity for consultation. This data sharing is covered by the *Data Sharing (Government Sector) Act 2015* and other key legislation which all agencies have requirements to comply with: *Privacy and Personal Information Protection Act 1998 (NSW)*, *Health Records and Information Privacy Act 2002 (NSW)*. Please refer to the guidelines for sharing information between government agencies.

[21] NSW Department of Primary Industries (2007). Endangered Ecological Communities in NSW: Lowland Darling River Aquatic Ecological Community (Primefact 173).

community gives all native fish and other native aquatic biota endangered species status. Fish deaths observed during the drought conditions of 2018-19 and following the flood conditions of 2023 pose a significant threat to this ecological community and are a clear indication of the stress this community is under from river regulation and development.

Monitoring undertaken by DPI Fisheries between 2019 and 2023 indicates the abundance of some native species has declined in the Lower Darling-Baaka River following the March 2023 fish deaths event.[22] Concurrently, there has been a significant increase in pest species (carp and goldfish) compared with surveys undertaken in 2019, 2020 and 2021, particularly in the Menindee Weir Pool.

The ongoing decomposition of fish and other aquatic biota that perished in early 2023 has elevated nutrients and biological oxygen demand in the Lower Darling-Baaka River, likely driving algal blooms observed in winter months during the course of this Review. These effects significantly elevate the risk of further fish deaths leading into the warmer months of spring and summer and suggest the existence of a feed-forward loop in this part of the river.

1.3 Impact of Fish Deaths on Community

The impacts of the fish deaths on the social, cultural, economic and physical and mental health of the local community or anyone connected with the Darling-Baaka River cannot be underestimated. The impacts were exacerbated in 2023 when two fish death events occurred close together, with the second event being the largest fish death event recorded in the Basin. These impacts were evident during the listening sessions conducted by the Review team in Menindee, where community members demonstrated their strong connection to and reliance on the river and lakes for all aspects of life. Traditional Owners noted their loss of connection to Country and loss of important protein sources through not being able to fish. Others noted the potential impact on water quality and its subsequent use for town water, crops and irrigation. A consistent comment from the entire community was the long-term decline in water quality and consequent reduction in the health of the river ecosystem

Feedback from both Traditional Owners and others is that fish death events of this magnitude are not natural. Historically, there are no storylines of mass fish deaths. They are a modern phenomenon caused largely by river regulation and development. Issues consistently raised during the Review include the longer term degradation of the Darling-Baaka River, reflected in loss of flows and native species, including culturally significant species, and increases and range expansion of invasive species.

Diminished amenity values and recreational opportunities, loss of domestic and stock access as well as direct and indirect impacts on businesses were also raised in consultation sessions. The stench of millions of dead fish for many was indescribable. The mental and physical burden was compounded by previous mass fish deaths, preceding years of significant flooding and drought, and broader economic challenges.

In addition to the events themselves, community reports to the Review team indicated the Government (emergency) response, including communications, compounded their distress. People reported feelings of anger, frustration, mistrust, exhaustion and alienation, stating that their deep knowledge and experience of the river system was overlooked or dismissed. They considered that the decline of the river ecosystem was unrecognised. ‘Review fatigue’ and cynicism was palpable, with the commonly cited concern being the lack of progress or implementation of recommendations from previous reviews.

An opinion that the Menindee Lakes system was used as a storage or pipeline for external interests was frequently raised, along with concerns for the degradation of the river and the loss of flows following the commissioning of the Wentworth to Broken Hill potable water pipeline and what was considered to be a growth in northern Basin irrigation.

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[22] Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

By contrast, the reciprocal arrangement between people and Country and the respect that should be afforded both the river and community was summarised by Traditional Owners as "healthy Country, healthy people". As described in '*Barka: the Forgotten River*', the '*Barka (the Darling River) is more than a body of water; Barka is a mother, an Ancestor, a life source, and in peril, along with everyone that lives along it*'.[23] The river is central to the culture and spirituality of the Barkandji people, with Western dating methods indicating a 45,000-year connection.[24] The deep connection to the Baaka is illustrated by Barkandji families' relationship to their totem, the bony herring (bream) or *nhaampa*. *Nhaampa* represented a large proportion of the March 2023 fish deaths, with their death akin to that of a family member for members of the Barkandji community.

Community members consistently commented on the significant and negative change in water quality over time. This included how clear the water once was, being previously able to swim in and drink directly from the river, catching fish, turtles and mussels. Traditional Owners also spoke to the Review team of the correlation between the degradation of the river and social impacts, including educational attendance and crime rates.[25] Water quality and access to water have also impacted the agricultural output of the Menindee area.

1.4 Review process

Following the 2023 fish deaths, the Hon. Rose Jackson MLC, Minister for Water and the Hon. Penny Sharpe MLC, Minister for the Environment, requested that the NSW Chief Scientist & Engineer (CSE) undertake an independent review into the two events in the Darling-Baaka River at Menindee. The Terms of Reference for the review is provided in Appendix 1.

To inform the Review, an expert panel was established. The Expert Panel comprised people with a range of expertise relevant to the health of rivers. The Expert Panel membership is at Appendix 2. In addition to formal panel meetings, members were consulted off-session and joined discussions with other experts and agencies as relevant to their expertise, some contributed written sections and performed fieldwork tasks as required. and. A summary of recommendations from previous reviews is at Appendix 3.

The Review team made site visits, met with the community, Aboriginal organisations, Government agencies other stakeholders and interested parties and made a call for submissions. The Review team also undertook preliminary sampling of river water and sediment.

1.4.1 Site visits and consultation

The Review team made four visits to Menindee (Appendix 4) which included a mix of 'drop in' community listening sessions as well as pre-arranged meetings held at the Civic Hall, other community locations and along the river. Consultations were mostly one-on-one, with community members sitting down with Review team members to share their knowledge and experiences.

Prior to and during site visits, contact was made with Aboriginal leaders, local residents and community groups. These meetings were deliberately informal and unstructured as a response to negative feedback from the community about previous 'town hall'-style meetings by Government agencies, that were perceived as being neither genuine nor effective two-way communication. Critical issues raised by community members about previous agency consultation processes included single-day fly-in, fly-out

[23] Australian Museum (2023). Barka: The Forgotten River.

[24] Janke, T. Cumpston, Z. Hill, R. et al. (2021). Australia State of the Environment 2021: Indigenous.

[25] This is reflected in literature, see for example "*… when the river is healthy, everything flows and Baakandji people are happy. However, when the river is sick the Baakandji people are sick both physically and socially. Crime rates, family violence and mental health issues rise when the Baaka doesn't flow*". *Source: Ellis, I. Bates, W(B). Martin, S. et al. (2021). How Fish Deaths Affected Traditional (Baakandji) and Non-traditional Communities on the Lower Darling-Baaka River. Marine and Freshwater Research 73(2), 259-268, and McCausland, R. and Vivian, A (2007). Why Do Some Aboriginal Communities Have Lower Crime Rates Than Others? A Pilot Study. Journal of Criminology 43(2), 301-332.*

approaches, lack of regard for local knowledge and a lack of opportunity to absorb or question material or plans, prompting one Elder to comment: "*They took our voices and gave nothing back*".

In addition to meetings, the Review team accepted invitations for an orientation tour of the lakes management infrastructure by WaterNSW and the MBDA, tours of sites having significance to Barkandji people by local Elders at both Menindee and Wilcannia, as well as sites recommended by residents. In addition to visiting areas on land, the Review team toured the ~40km stretch of river between Wier 32 and Main Weir by boat.

The Review team also met with Government agencies and organisations. A list of agencies consulted is at Appendix 4.

During the site visits, listening session and meetings, the Review team gained valuable insights and information to inform the review. This included potential contributing causes of the fish deaths, impacts from the fish deaths on the community, concern over the health of the river and water quality, community engagement – both in general and during the fish deaths – and lack of action to mitigate against future fish deaths.

The Review team sincerely thanks all those who generously shared their time, experience and expertise. The insights and information gained greatly assisted the review process and has shaped the content, scope and findings of this Review.

1.4.2 Submissions

The Review sought submission from people on any matter related to the Review Terms of Reference, especially those affected by or living in the communities that were impacted by the fish deaths. Short email submissions through to full submission either as documents or video files were accepted. Verbal submissions were also welcomed during the site visits, which were documented by the Review team. Any party who provided a submission could request for their submission to remain confidential.

Twenty-nine written were received from individual community members, community and industry representative groups, scientists and Government agencies. Of these, two were marked confidential. The remaining 27 are published on the website of the NSW Chief Scientist & Engineer, with a list at Appendix 5. Many submissions were of high scientific or observational quality and of great help to the Review team.

Submissions expressed concern over the recent fish deaths events in 2023, asked that steps be taken to mitigate against future events and noted the importance of good water quality and a healthy river. Other common themes included:

- water flows and passage across the Murray Darling Basin
- fish passage across the Lower Darling-Baaka River and Menindee Lakes system
- fish species present in the river and system, include types and changes in population
- impact of carp and other introduced fish species on native fish, aquatic plants and the river health in general
- need for monitoring and data to inform decision making.

Submissions provided their insights and opinion on:

- the causes of and the response to the fish death events, and ideas for improvement
- the use of local knowledge to support water management and responding to adverse events
- changes in riverine flora and fauna.

Some submissions expressed concern over:

communication and engagement with the local community during the fish deaths event
water management including allocation and usage
the use of environmental water when responding to water quality issues
the impact of land run-off on river health
future impact on the system due to a changing climate.

All submissions were reviewed by the Review team, shared with the Expert Panel and directed avenues of further enquiry by the Review.

1.4.3 Sediment and water analysis

Sediment and water sampling was undertaken by the Inland Fisheries Research Group from Charles Sturt University, Albury. The Group sought to determine whether a 'rapid assessment' approach to water chemistry and quality could be performed in a manner that could establish a long-term baseline of data for the Menindee region. Analyses of water and sediment samples are detailed at Section 2.6.3.

1.5 Structure of this Report

Chapter 2 considers the sequence of events and causal factors contributing to the 2023 fish deaths, including environmental conditions in the period leading up to the event.

Chapter 3 proposes an integrated suite of strategies to reduce the risk of further mass fish deaths and restore the health of the broader river ecosystem.

Chapter 4 examines water management governance, policy and operations and recommends improvements to the regulatory framework to give effect to environmental protections and improve whole-of-catchment ecosystem health.

Chapter 5 discusses the emergency response to the mass fish deaths and recommends improvements to the emergency management framework.

Chapter 6 contains a summary of detailed recommendations.

2. Fish deaths: causal factors and sequence of events

The most likely (proximate) cause of the mass fish deaths – consistent with available data – was hypoxia, resulting from low dissolved oxygen (DO) in the water column. Low DO can be driven by a number of factors including: flow rates, temperature, the presence of algae, a large number of fish in enclosed areas (biomass) and poor overall water quality – all of which are considered in the Review. However, mass fish deaths are also symptomatic of a degradation of the broader river ecosystem over many years. The long-term decline in the health of the Lower Darling-Baaka River has set the preconditions in which other causal factors – flow rates, temperatures, presence of algae, excessive number of fish – have tipped the river ecosystem into a low dissolved oxygen state with consequent mass fish deaths.

Changes to flow regime and fish passage from water infrastructure and altered water use in the northern Basin are likely key factors in decreasing water quality, the decline of native species, and the susceptibility of this section of the river to mass fish deaths.

2.1 Acute causal factors

The Review considered the conditions leading up to the mass fish deaths observed in the Menindee weir pool between Main Weir and Weir 32 in March 2023 and examined a number of possible causes for the mass fish deaths including: hypoxia, acute toxicity, blackwater associated with flood recession, thermal destratification, high temperature and algal bloom crash. Based on available data it is difficult to assign a definitive, unequivocable cause for the mass fish death events. However, most of the possible causes considered were ruled out through being inconsistent with analysis of available data, other information about when these conditions occur and their impacts.

The most likely (proximate) cause of the mass fish deaths – consistent with available data – was hypoxia, resulting from low dissolved oxygen (DO) in the water column. Low DO occurred when oxygen demand in the weir pool exceeded available supply. This was driven by a confluence of factors, including: high biomass (particularly carp and algae), poor water quality, reduced inflows and high temperature. While low DO was the likely immediate driver of the fish deaths, gaps in monitoring make it difficult to ascertain the exact DO conditions in the Weir 32 weir pool with sufficient spatial or temporal resolution. DPE-Water conducted DO testing in the weir pool on 14 March following water quality concerns at the time (Figure 6). The results showed critically low DO levels, which were reflected several days later downstream at the permanent Weir 32 monitor. (Figure 7)

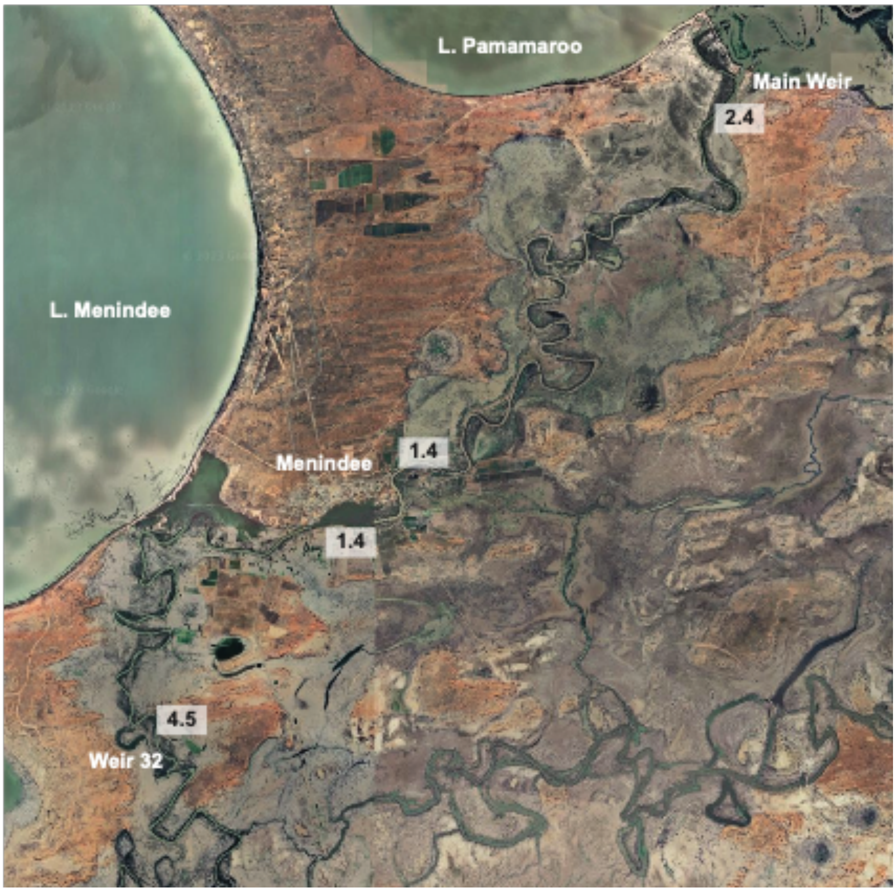

Figure 6: Dissolved oxygen levels (mg/L), 14 March 2023. *Source data: DPE-Water Water Quality Update (15 March 2023), Murray-Darling Basin – Water quality and dissolved oxygen results.*

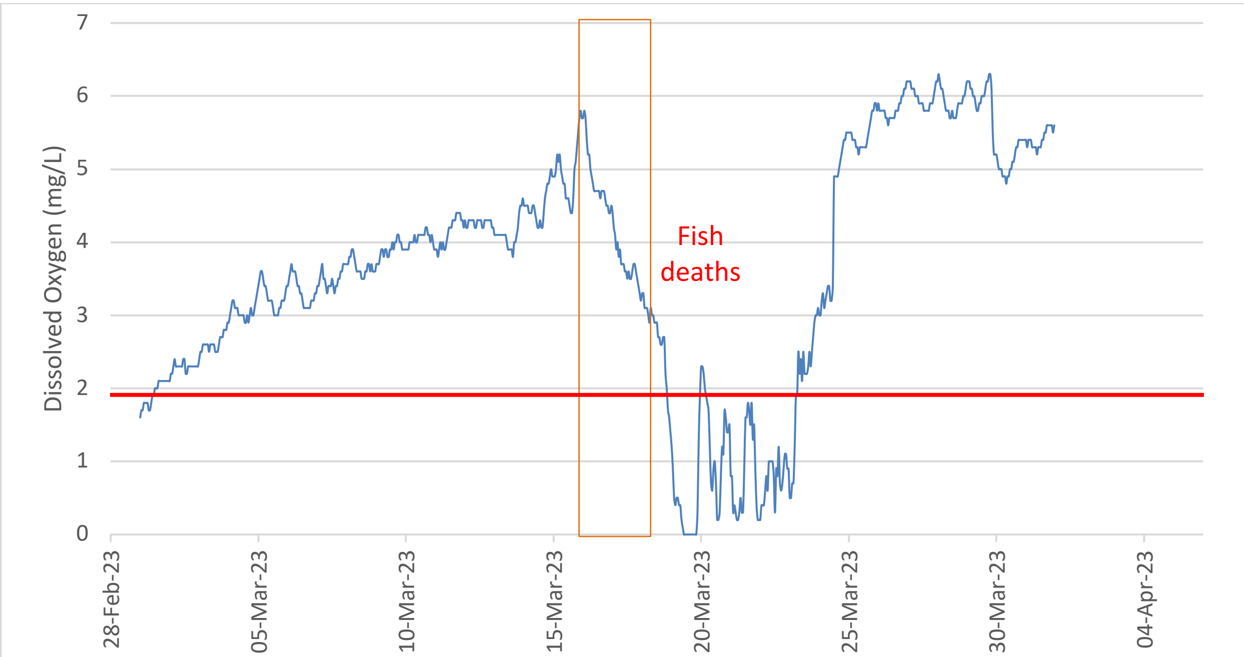

Figure 7: Weir 32 dissolved oxygen levels (mg/L), March 2023. Red line indicates critical DO level for fish survival. *Source data: WaterNSW. DO measurements taken from continuous hourly data.*[26]

[26] Note that Weir 32 is downstream of the weir pool so DO levels at this location are a lagging indicator of conditions in the upstream reaches of the full ~40km stretch of the weir pool.

Following the fish deaths, the EPA collected water samples for testing and additional temporary DO daily monitoring sensors were deployed along the reach between the Lake Pamamaroo outlet and Weir 32. WaterNSW also completed 18 longitudinal profile runs and 13 days of vertical profiles between 22 March and 27 June 2023 (Figure 8).

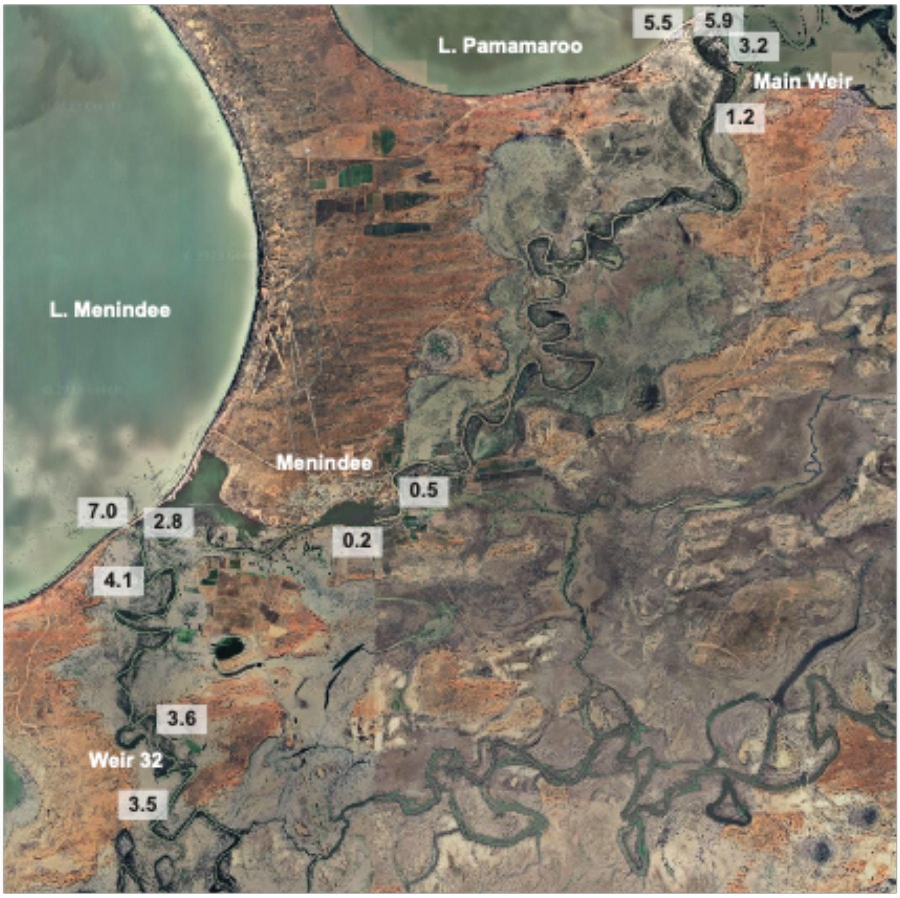

Figure 8: Longitudinal DO at various sites near Menindee. Samples are from March 22 2023, several days following mass fish death. *Source data: WaterNSW.*

Limited data collected by the EPA at the time of the March fish deaths (and subsequently) does not support the presence of toxins or poisonous substances in the water column or in fish carcasses. Similarly, there is little evidence for the presence of fish pathogens likely to cause the sudden, widespread death of fishes on the scale observed. Analysis of water flow data indicates the flood recession pulse had passed the weir pool at the time the fish perished and the flow velocities at the time were high enough to exclude stratification as the likely cause. While both water and air temperatures were high at the time the fish died, the restricted localisation of the mass deaths cannot be explained by temperature alone, even though elevated temperature was a likely contributor to lowering oxygen availability in the water column.

A range of factors contributed to the hypoxic conditions and stress placed on aquatic biota in mid-March, including:

- An estimated large fish biomass had accumulated in the weir pool with a high associated oxygen demand, attracted to the weir pool flood recession flow in January/early February and releases of well oxygenated water (~4,300ML/day) from Lake Pamamaroo in early March (Figure 9). The number of fish that perished is estimated given the actual biomass prior to the event is unknown and difficult to quantify in retrospect. A lack of fishways (or effective alternative fish passage pathways to allow fish to move from the impacted reach and into the upper lakes) also likely contributed to the large number of fishes in the weir pool.
- The accumulation of fishes was followed by reduced inflows from the upper lakes, particularly oxygenated water from Lake Pamamaroo, associated with flood recession operations and exhaustion

of the Lower Darling EWA. Combined releases from the upper lakes, mainly Pamamaroo, fell to 1,315ML on 16 March 2023 while Lake Menindee releases were 3,945ML.

- High algal biomass accumulated in the weir pool in the lead up to the event with associated diurnal variations in dissolved oxygen levels. The Review notes, however, there was a gap between algal sampling, despite the high algal loads observed upstream of Weir 32 in late February 2023.
- Elevated air and water temperatures were present, which likely affected the dissolved oxygen in the water column.

The combined oxygen demand from the fish biomass, algae and sediment on the night of 16 March exceeded available oxygen supply (Figures 9 and 10).

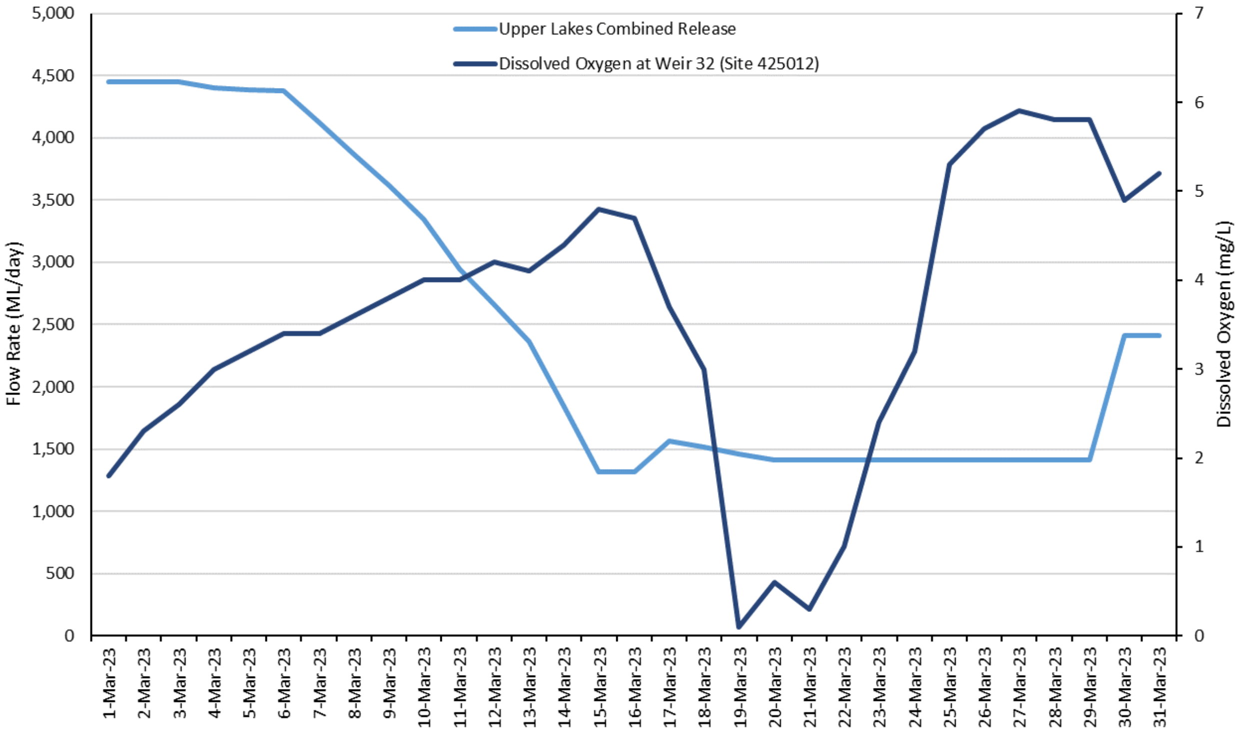

Figure 9: Dissolved oxygen at Weir 32[27] and upper lakes releases in March 2023. *Source data: WaterNSW.*[28]

[27] Weir 32 is downstream of the main reach of the weir pool where the fish deaths were observed. There was no DO monitoring directly in the weir pool at the time. As such, there would be a time lapse between the sag in DO at Weir 32, when releases fell to 1,315ML, and when the fish deaths were observed.

[28] Note: During March, most of the upper lakes releases were from Lake Pamamaroo. Flows from Lake Wetherell ranged between 65 and 100ML/day during March. DO data is from Site 425012 hourly data via WaterNSW Water Insights. The 9am data point is plotted for each day in March.

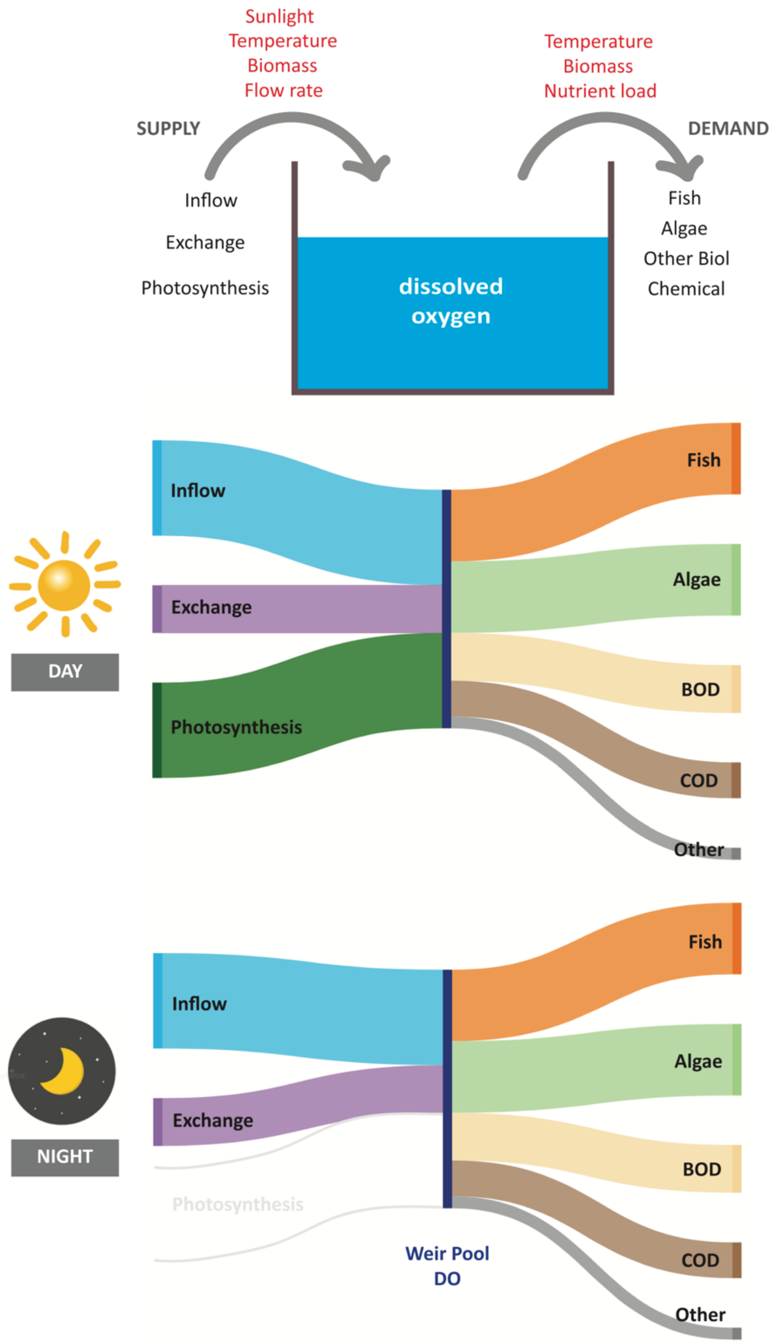

Figure 10: Conceptual model of dissolved oxygen balance in Menindee (Weir 32) weir pool. Primary sources of oxygen supply and drivers of oxygen demand are shown, along with factors influencing these. Flow charts compare DO balance, showing supply and demand factors during day and night. Algae become nett consumers of oxygen at night as photosynthesis ceases, causing significant decreases in DO. (Relative size of supply and demand factors are illustrative only). *Source: OCSE.*

2.2 Sequence of events

Figure 11 depicts the conditions leading up to and including the 2023 fish deaths. Further detail of the conditions for each time period follows, noting that the fish accumulation may have occurred over a period of months or years.

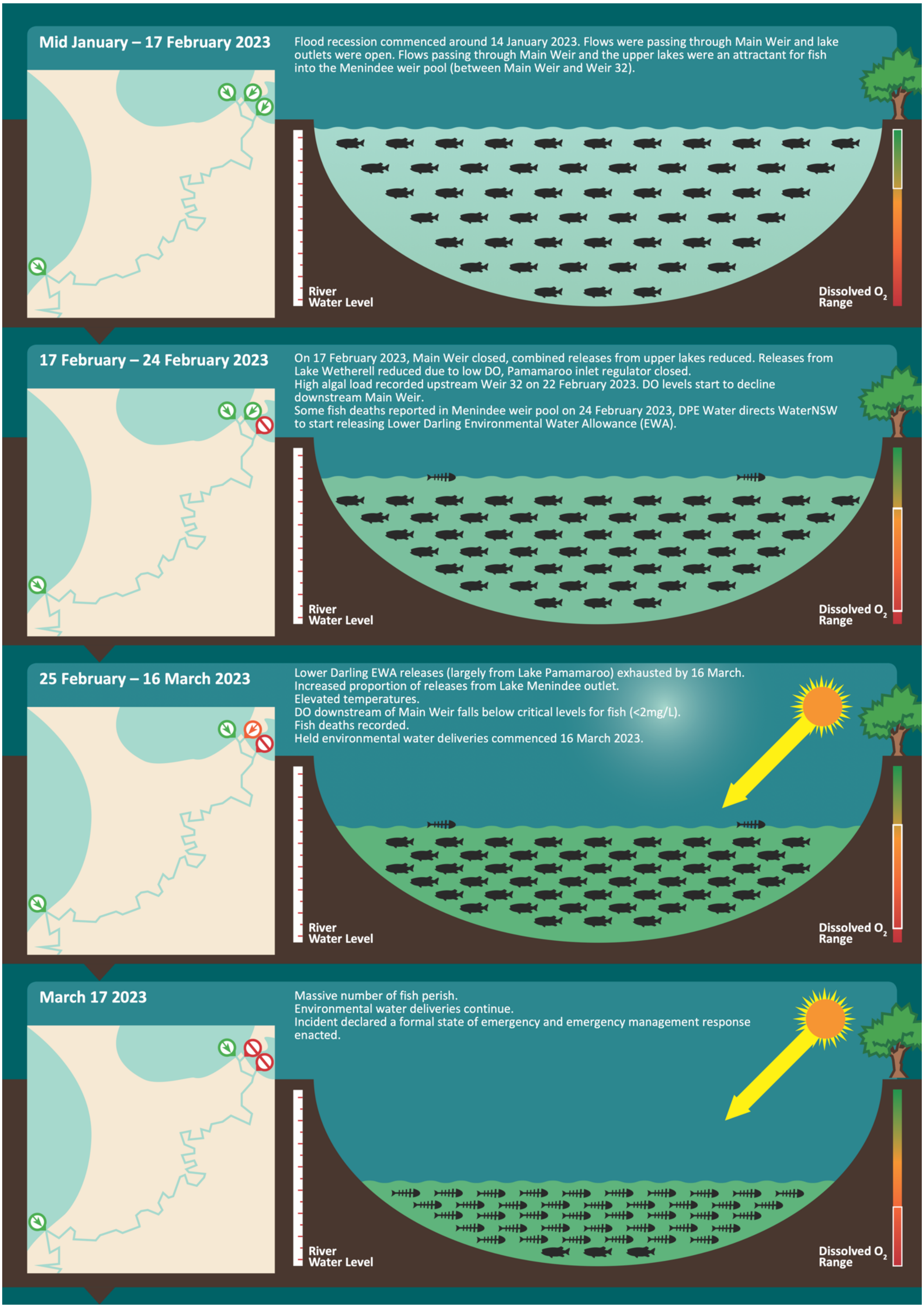

Figure 11: 2023 fish deaths timeline, highlighting key contributing factors. Conditions affecting supply and demand of oxygen in the lead up to the 2023 fish deaths. *Source: OCSE.*

2.2.1 Fish recruitment over La Niña period (2020-23)

Conditions leading to the February-March 2023 fish deaths contrast to the climatic conditions associated with the 2018-19 events, which occurred during the worst three-year drought on record (2017-2020) for the region. La Niña weather conditions mid-2020 to early 2023 resulted in significant and widespread rainfall and subsequent flooding across much of the Murray-Darling Basin.

The flooding connected the Menindee Lakes and the Lower Darling-Baaka, and caused extensive riparian and floodplain inundation: conditions that support fish breeding, recruitment and dispersal. Prolonged high flows between 2021 and 2023 and associated releases from Menindee Lakes likely attracted fish into Menindee weir pool.[29] The abundance of bony herring – a 'boom, bust' species that formed a significant portion of the biomass observed in the March 2023 fish death event – can increase significantly during wetter periods such as those experienced in 2020 to early 2023.[29]

Based on surveys undertaken by DPI Fisheries, native and pest species that benefited from the flood conditions and increased in abundance prior to the March 2023 fish deaths include common carp, bony herring (*Nematalosa erebi*), goldfish (*Carassius auratus*), Australian smelt (*Retropinna semoni*), freshwater prawns and yabbies (*Cherax destructor*). Golden perch were reported to have benefited from flood conditions but were still well below their pre-2018 (drought) levels.

2.2.2 Moving into flood recession (Mid January to 17 February)

In the lead up to the fish deaths, WaterNSW was operating the Menindee Lakes Storage and associated infrastructure in accordance with the operating rules in its work approval. Flood operations, including the opening of Main Weir, were likely an attractant for fish into the reach between Main Weir and Weir 32. However, as part of flood recession operations, Main Weir was closed on 17 February 2023 and the Menindee lakes returned to full supply level on 28 February 2023.

A lack of fishways and closure of the Main Weir (which would have been providing passage) impacted the ability of fish to move into the upper lakes, leading to congestion between Main Weir and Weir 32. Fish were likely still attracted to the upper reaches by releases from the upper lakes during this period. The volume of fish biomass that accumulated between Main Weir and Weir 32 preceding the fish deaths was unknown, but the mortality figures indicate it was both significant and underestimated.

Concerns regarding low dissolved oxygen levels in Lake Wetherell (measured just upstream at Nelia Gaari Station – site 425060) and also in the Darling River upstream of Weir 32 (425012)[30] in February 2023 were raised with the Hypoxic Blackwater Working Group (HBWG).[31] Low dissolved oxygen levels in Lake Wetherell were likely associated with hypoxic blackwater that had moved down the Barwon-Darling River from tributaries in the northern Basin.

2.2.3 Concerns regarding water quality and some fish deaths (18 February to 24 February)

In February 2023, low dissolved oxygen levels were recorded upstream of Lake Wetherell at Nelia Gaari Station (425060). Water potentially low in dissolved oxygen was being released from Lake Wetherell outlet into the river at the top of the weir pool as part of flood recession operations. This likely contributed to a decline in dissolved oxygen in the upper weir pool. Water from Lake Wetherell was also being diverted to

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[29] Stocks, J.R., Ellis, I.M., van der Meulen, D.E. et al. (2021). Kills in the Darling: Assessing the impact of the 2018–20 mass fish kills on the fish communities of the Lower Darling-Baaka River, a large lowland river of south-eastern Australia. *Marine and Freshwater Research 73*(2), 159-177.

[30] Dissolved oxygen in Lake Wetherell and upstream Weir 32 fell to critically low levels in mid-February (2.01mg/L on 12 February 2023 on the Darling-Baaka River upstream Weir 32).

[31] The Hypoxic Blackwater Working Group (HBWG), comprises NSW and Commonwealth agencies and makes decisions around maintaining water quality within the Darling-Baaka.

Lake Pamamaroo with some short circuiting of the water from Lake Wetherell to Pamamaroo going directly into the weir pool.[32]

Dissolved oxygen in the Darling River upstream of Weir 32 was below 4mg/L for much of February. This likely contributed to fish deaths observed below Main Weir around 24 February 2023.

In order to reduce water low in DO from entering both the weir pool and Lake Pamamaroo from Lake Wetherell, WaterNSW was instructed to close the regulator between the lakes and reduce releases from Lake Wetherell outlet. WaterNSW was also instructed to reduce releases from Lake Menindee to mitigate the risk of backflow occurring which could trap deoxygenated water in the upper weir pool.

In consultation with the Hypoxic Blackwater Working Group, DPE-Water placed an order for the release of planned environmental water (Lower Darling Environmental Water Allowance) on top of the flood recession flows. This began on 24 February with the intent to improve dissolved oxygen and mitigate further fish deaths.

2.2.4 Environmental water used, oxygen demand increases, mass fish deaths (24 February to 17 March)

The environmental water releases from 24 February (largely from Lake Pamamaroo) provided a short-term benefit, mitigating further fish deaths in early March. However, in March, releases from the upper lakes reduced. Several days prior to the fish deaths, releases increased from the Lake Menindee outlet, which enters the lower part of the weir pool. On 16 March, combined releases from the upper lakes, mainly Pamamaroo, fell to 1,315ML while the Lake Menindee outlet released 3,945ML (Section 2.3.2).

The EWA (30GL) was exhausted by 16 March, the day of the mass fish deaths, so environmental water holdings (The Living Murray, CEWH, NSW) were then called upon to alleviate the deteriorating water quality situation.

At the time, both air and water temperatures were high in Menindee. The daily maximum air temperature increased to 37°C on Thursday 16 March, which is 6.2°C above average, and to 42.6°C on Saturday 18 March, 11.8°C above average. As air temperature increased, water temperature increased, reaching approximately 25°C on 16 March 2023 in the Darling-Baaka River upstream of Weir 32. Water temperature and dissolved oxygen have an inverse relationship – the ability of oxygen to dissolve in water decreases with increasing temperatures. Further, as temperatures increase, the biochemical oxygen demand (BOD) of organisms increases as their metabolic and respiratory rates increase.

An increase in algal biomass leading up to the time of the fish deaths is potentially associated with nutrient recycling from the large biomass of fish in the weir pool, which would have contributed to an observed night-time decrease in dissolved oxygen levels as respiratory demand increased. On 22 February 2023, total algal biovolume was high (10.51mm^3/L). It was not sampled again until after the fish deaths. Total algal count for 21 March at Weir 32 was not recorded, but algae become a nett consumer of oxygen at night in the absence of photosynthetic oxygen production.

The combination of high algal biomass, high water and air temperatures, and changes to flows through the weir led to a deterioration of water quality and hypoxic conditions in the weir pool as oxygen demand outstripped supply. This confluence of conditions likely caused the large-scale fish deaths observed on 16 March 2023. The fish deaths were the largest observed mass fish death event in the region. It is estimated some 20-30 million fish perished.

2.3 Dissolved oxygen and flow management

2.3.1 Dissolved oxygen

The Review understands the transition from extreme drought to flood was one of the quickest in recent history. A sudden onset of flooding after extreme drought can lead to release of large amounts of

[32] Baldwin, D (2023). Proximate Cause of the Fish Deaths in Weir 32 Weir Pool (Menindee) in March 2023 *(Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee)*.

dissolved organic carbon, which contributes to oxygen demand via microbial breakdown of organic material. This process, known as a “blackwater event”, occurs over a longer period after extensive drought compared to the rapid flushing caused by floodplain inundation.

In late 2022 to early 2023, hypoxic conditions were observed in several rivers in the Murray-Darling Basin including both the northern Basin (lower Gwydir, Darling River) and southern Basin (the Murray, Wakool, Niemur, Kolety/Edward River). DO levels were particularly low within the Darling-Baaka River from Bourke to Wilcannia, where critical levels were reported, potentially impacting fish health.[33,34] There were reports of fish struggling or dying and Murray crayfish and shrimp exiting the water across the Darling-Baaka. The critical minimum level of DO varies among fish species, and their size and physical condition. It is generally considered that native fish are seen gasping at the water surface when DO drops to around 2mg/L and have difficultly surviving when DO drops lower than this. However, DO levels below 4 - 5mg/L are typically not well tolerated for prolonged periods.[34]

Oxygen levels in the upper reaches of Lake Wetherell and the Darling-Baaka River downstream of the Lakes at Weir 32 and Burtundy remained in the ‘safe’ range for fish health during late 2022 and early 2023. However, blackwater could be seen in early January originating from Lake Wetherell and pushing into Lakes Tandou and Pamamaroo, where it mixed with turbid water held in the lakes.

Floods in the upper Darling catchment resulted in further deoxygenation of water from February onwards, with low DO levels and some fish deaths reported on 24 February 2023 below Main Weir and upstream Pooncarie. The HBWG advised for the release of the 30GL Environmental Water Allowance to address water quality issues, which started on 25 February and continued until 16 March 2023.[35] The HBWG also requested WaterNSW to undertake additional DO monitoring in the river between Main Weir and Weir 32 and close the regulator between Lake Wetherell and Pamamaroo (it was closed by 25 February) with an aim to temporarily reduce low DO water entering Lake Pamamaroo outlet and being discharged into the weir pool. These actions resulted in slightly improved DO and no further fish deaths in early March. The inlet regulator was reopened on 20 March to allow the water levels between Lakes Wetherell and Pamamaroo equalise in order to retain infrastructure integrity.

By the start of March, WaterNSW continued to release water from Lake Pamamaroo and Lake Menindee. Reinstallation of fishway baffles through Pamamaroo inlet was underway with an aim to reduce fish deaths in the weir pool. Fish deaths were reported on 16 March in Menindee town weir pool. The lakes did provide some refugia for smaller fish and crustaceans as DO conditions deteriorated in Lake Wetherell.

Dissolved oxygen at Weir 32 had been above the safe level for fish health but decreased rapidly early on 17 March 2023, dropping to below 1mg/L, coinciding with the fish deaths at Menindee upstream (Figures 6 and 7). Oxygenated water was being released from Lake Menindee to dilute the poor-quality water coming down the river, however, DO levels between Weir 32 and Pooncarie remained below the safe levels for fish health as low oxygenated water continued to make its way downstream.

Post fish death, WaterNSW continued daily DO monitoring and EPA undertook sampling within the Lakes that included DO monitoring. As at 23 March 2023, the lowest DO readings were in the river from Menindee down to the junction of the Darling-Baaka and Menindee Creek (1.70mg/L). These low DO results indicated risk of further fish deaths in this area and downstream. The DO result from near the water surface at Weir 32 (which is set at a fixed depth lower in the water column of the weir pool) was higher than the readings from the continuous sensor at the gauging station. The low oxygen water was being diluted as a result of turbulence from the high flow velocity mixing oxygen throughout the whole

[33] NSW Department of Planning and Environment (2022). Murray-Darling Basin – Water Quality Update – 14 December 2022 – water quality and dissolved oxygen results.

[34] NSW Department of Planning and Environment (2023). Murray-Darling Basin – Water Quality Update – 11 January 2023 – water quality and dissolved oxygen results.

[35] WaterNSW (2023). Submission: Independent Review into the February-March 2023 Fish Deaths in the Darling-Baaka River, Menindee.

water column. The reading of 4.40mg/L at the town railway bridge was taken near the water surface, indicating there was some oxygen replenishment from the atmosphere. However, readings taken deeper in the water column show oxygen levels quickly dropped below 2mg/L at around 60 cm.[36]

2.3.2 Management of flows from Menindee Lakes

In January and February, leading up to the fish deaths, WaterNSW was operating the Lakes as a controlled recession in accordance with the operating requirements of its works approval.

From January, flood recession flow over Main Weir gradually reduced from around 75,000ML/day on 1 January 2023 (not shown on the graph) to 10,000ML/day by 9 February and 4,500ML/day by 14 February 2023 (Figure 12). Main Weir was closed on 17 February. During this period, lower quality water from Lake Wetherell was being released into both the weir pool and Lake Pamamaroo via the inlet while oxygenated water from Lake Pamamaroo was also being released into the weir pool (Figure 13). There was also some short circuiting of water observed from Lake Wetherell into the weir pool.[37]

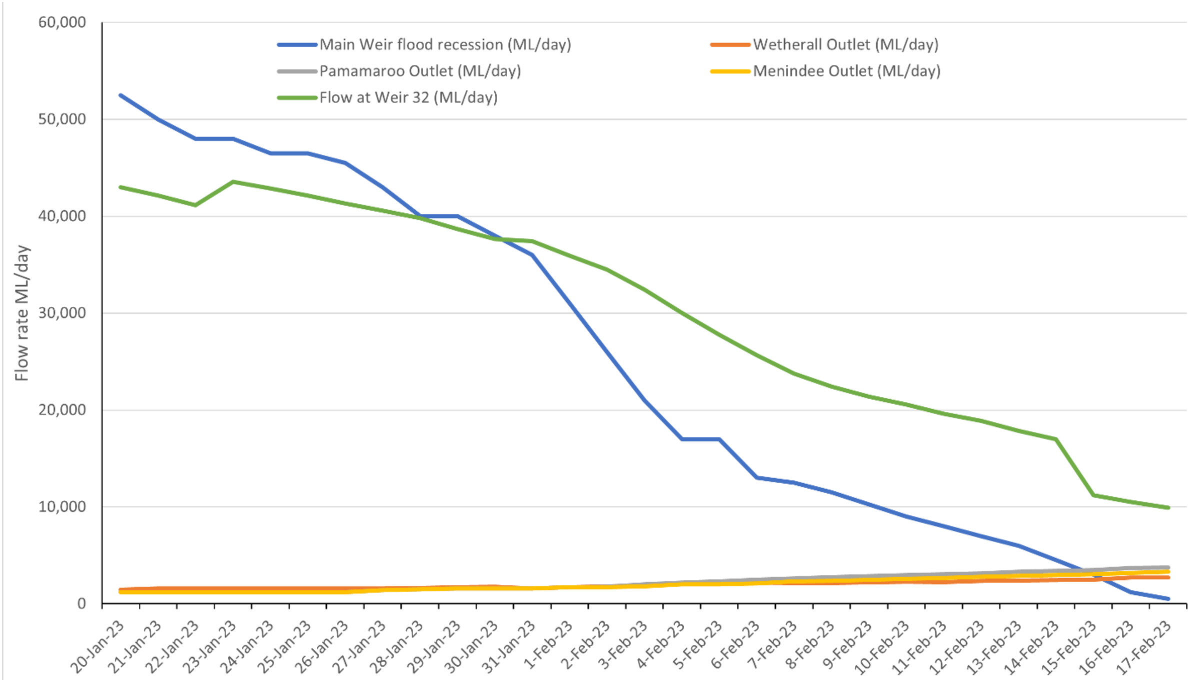

Figure 12: Menindee Lakes outlet flows 20 January - 17 February 2023. Figure includes flood recession flow over Main Weir over this time. Note the Main weir was closed on 17 February 2023. *Source: WaterNSW.*

[36] NSW Department of Planning and Environment (2023). Murray Darling Basin – Water Quality Update – 23 March 2023 – water quality and dissolved oxygen results.

[37] Baldwin, D (2023). Proximate Cause of the Fish Deaths in Weir 32 Weir Pool (Menindee) in March 2023 *(Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee)*.

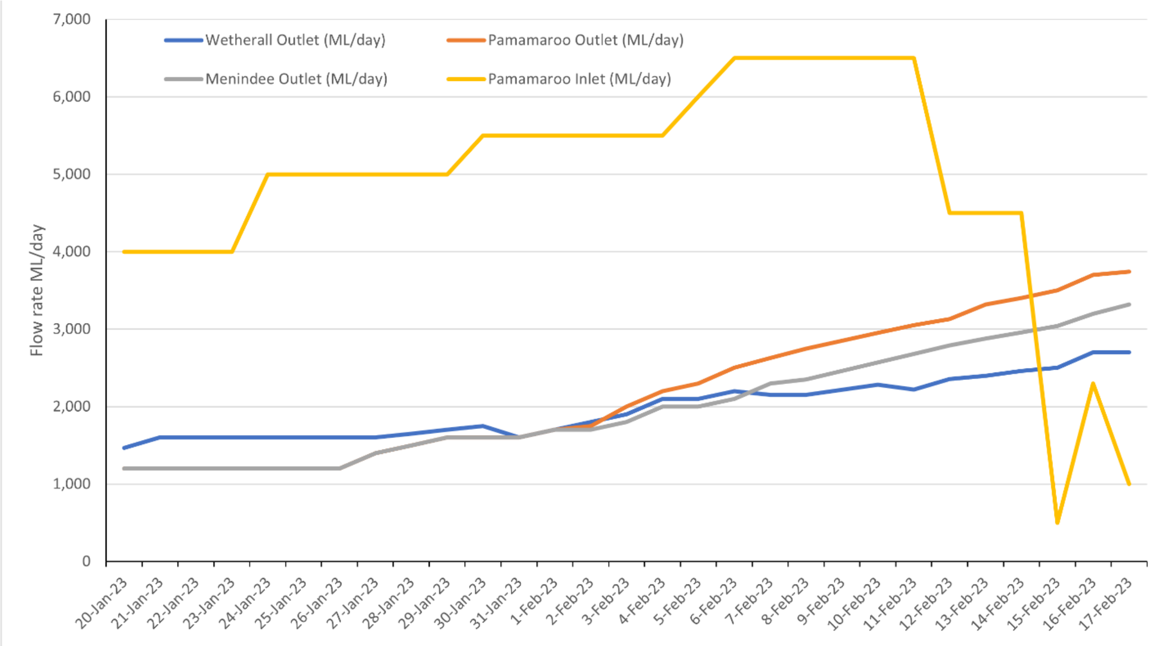

Figure 13: Menindee Lakes outlet flows from 20 January to 17 February. Flows of water from Lake Wetherell to Lake Pamamaroo via the Pamamaroo inlet. *Source data: WaterNSW.*

Between 17 February and 24 February, WaterNSW continued to reduce operational flows and releases from the upper lakes amid rising concerns about poor water quality in the weir pool. During this time, releases from Menindee Lakes slightly increased (Figure 14). On 25 February Lake Pamamaroo Inlet was closed, stopping the flows of lower quality water from Lake Wetherell into Lake Pamamaroo.

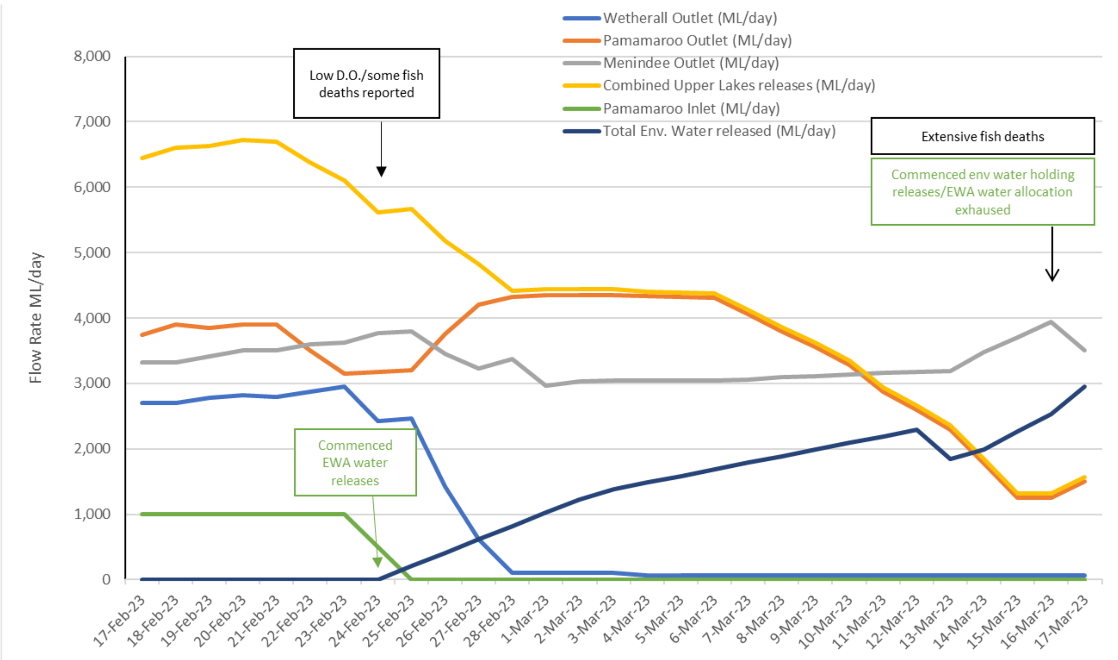

Figure 14: Menindee Lakes outlets and total Environmental Water releases 17 February - 17 March 2023. *Source* **data***: WaterNSW.*[38]

[38] Note that Main Weir was closed during this entire period. Water from Lake Wetherell outlet had low DO levels, water from Lake Pamamaroo outlet was well oxygenated and water at Pamamaroo Inlet was low DO water from Lake Wetherell mixing into oxygenated water in Lake Pamamaroo. Releases of environmental water from 25 February through 16 March consisted of the total 30GL of EWA Planned Environment Water.

However, with low dissolved oxygen levels and some observed fish deaths around 24 February, DPE-Water sought agreement from the Hypoxic Blackwater Working Group to use the Lower Darling Environmental Water Allowance. WaterNSW was directed to make releases above operational requirements to help improve dissolved oxygen levels downstream of Main Weir in the Weir 32 weir pool.

Figure 14 shows the releases from the different outlets between 17 February (when some fish deaths were observed) and 17 March when the mass fish death event occurred. Over this period releases from the upper lakes continued to decline significantly while releases from the Menindee Outlet below the weir fluctuated but remained between 3,000 and 4,000ML/day. Some of the reduced upper lakes releases were due to the closure of Lake Wetherell outlet by 1 March, to stop the poorer quality water from that lake going directly into the weir pool. But there was also a significant reduction in releases from Lake Pamamaroo outlet (well oxygenated water) from around 6 March, i.e. during the period that reliance on the EWA was increasing and the operational flows were decreasing. Note that operational flows rapidly declined from 10,000ML/day on 17 February to 350ML/day by 22 March.

In the beginning of March, there were no fish deaths reported and some improvements in dissolved oxygen levels were observed at Weir 32. These improvements followed the closure of the Lake Wetherell outlet, increased flow from Lake Pamamaroo and reduced flows from Lake Menindee outlet. By the second week in March, flows from Lake Pamamaroo started dropping and Lake Menindee outlet flows increased. On 16 March, 3,945ML was released from Menindee outlet below the weir pool while only 1,315ML was released from the upper lakes (65ML from Lake Wetherell; 1,250ML from Lake Pamamaroo). This was the day of the highest differential between Lake Menindee outlet and the upper lakes releases. Of this, 1,750ML was operational flows and 2,531ML was environmental water.

While environmental water was being released to help with water quality in the weir pool, the volume being released from Lake Menindeee was much higher than those being released from the upper lakes, particularly around 16 March. The reduction in upper lakes releases and higher releases from Lake Menindee outlet likely contributed to water backing up in the weir pool and trapping deoxygenated water into the stretch of river already containing a high fish biomass. Several local residents reported the river "flowing backwards" during this time.

Releases from Lake Pamamaroo rose again in late March 2023 and have dropped since. The response of water quality to inflows from the upper lakes, namely Pamamaroo, indicates the importance of managing the lakes on an event basis and ensuring the upper lakes can be drawn on when there is a critical water quality and/or an imminent fish death event. Decisions made about release locations over the months prior to the fish deaths had significant implications for water quality, particularly on DO levels. This highlights the importance of considering flow through the weir pool at Menindee, not just on water delivery over the metering point at Weir 32. Further regard should be paid to the potential for adverse outcomes on both the water quality and aquatic biota when this operator discretion is exercised.

2.3.3 Use of environmental water

Figure 15 highlights the use of the EWA and environmental water holdings compared with operational flow from mid-February through June. The EWA was exhausted on 16 March, at which time there was a shift to reliance on environmental water holdings to respond to the fish deaths and water quality issues. From late March to the end of June, operational flows reduced to around 300-350ML/day while environmental water use dominated, particularly in the late March/early April response period. Further details regarding the EWA are provided in Section 4.3.2.

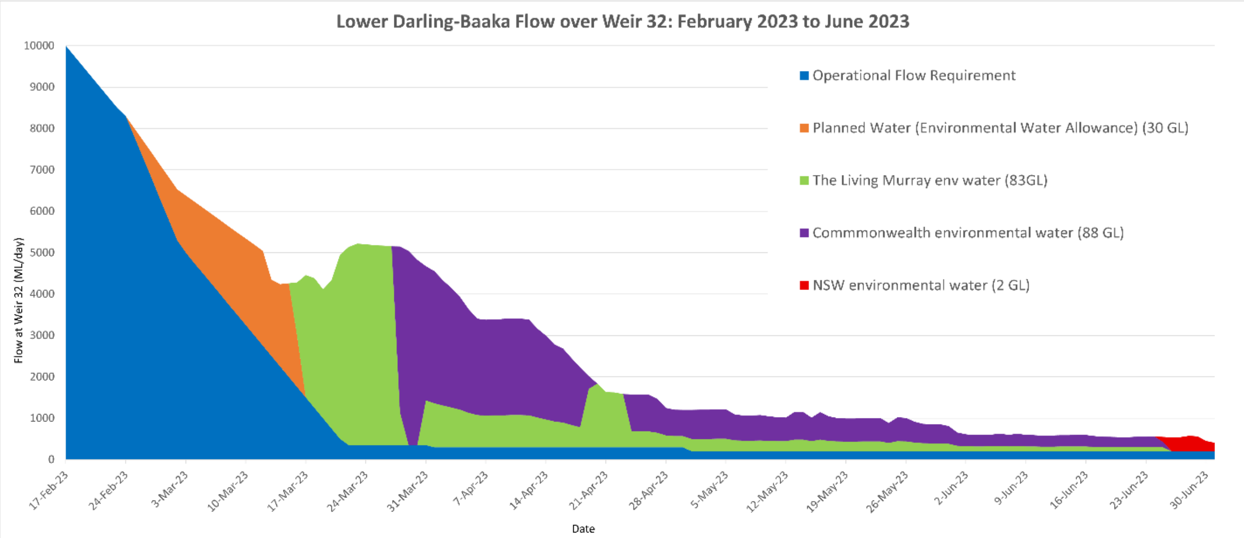

Figure 15: Total flows over Weir 32 (mid-Feb to June 2023). *Source: Commonwealth Department of Climate Change, Energy, the Environment and Water.*[39]

The combined volume of water from the Lower Darling EWA, The Living Murray Program, Commonwealth and State environmental water holdings used to manage the event through 30 June 2023 was 203.5GL. The Living Murray Program and Commonwealth environmental water holdings comprised the majority of environmental releases.

The Lower Darling EWA (shown in orange in Figure 15) comprised just 15% of the environmental water released from Menindee Lakes to mitigate hypoxic conditions and fish deaths. The current EWA provision is unlikely to be sufficient for mitigating future events of this scale, particularly if there is significant fish biomass in Weir 32 weir pool and a lack of suitable fish passage into the upper lakes. Further, the EWA is also only available when the volume of the lakes is above 640GL. Relying on environmental water to manage future water quality issues is an ongoing concern, with both direct and opportunity costs from its intended use (see Section 4.3).

2.4 Environmental conditions immediately preceding the 2023 events

Climatic conditions leading up to the March 2023 fish deaths were quite different to those surrounding the 2019 fish deaths. An El Niño event and extreme drought conditions coincided with the 2019 fish deaths, while a La Niña event and significant flooding preceded the 2023 fish death. However, both events were associated with elevated air and water temperatures at the time.

La Niña and a negative Indian Ocean Dipole event were present for three years (July 2020 – March 2023),[40] resulting in significant and widespread rainfall and subsequent flooding across the Murray-Darling Basin in spring and summer 2022-23. Three successive major flood surges in Menindee over 2022-2023 produced significant and compounding impacts on the management of the Lakes.[41] It was reported that flooding in Menindee and the surrounding township occurred because there wasn't enough storage for

[39] This shows proportions accounted against different sources. EWA was the predominant source of flows over Weir 32 after the fish death event. **MDBA Disclaimer:** MDBA does not warrant that the above data or the data capturing process is free from errors. The above operational estimate is based on operational records and does not reflect any rating table updates post facto, and/or actual irrigator extraction below Balranald, which may be different to the water order information used in the estimation. In addition, accounting splits among water holders in late June are indicative. Any discrepancy with reported volumes used will be within a small number of megalitres to the preliminary figures shown.

[40] BOM (2023). Financial Year Cimate and Water Statement 2022-23 – Australia's temperature, rainfall, water, oceans, significant weather and influences from 1 July 2022 to 30 June 2023.

[41] The major flood event experienced around the Menindee township reached peak levels in January 2023, which was close to exceeding the record 1976 flood levels (reaching 10.47m).

excess water to be captured or time for the water in the lakes to be released safely from the large inflows.[42]

Dry conditions across NSW in January allowed river levels to fall and flooding started to subside across inland catchments. However large inflow volumes persisted for several weeks, with major flood warnings remaining for the Darling-Baaka River at Tilpa, Wilcannia and Menindee. Falling river levels saw water that had been sitting out on the floodplain drain back into main river channels. The flood waters likely contained elevated dissolved organic carbon (DOC) released from inundated flood plain soils and organic matter. Agencies reported during this time the potential risk to fish health, both in them becoming stranded in disconnected water bodies and also potential exposure to declining water quality and dissolved oxygen, higher air and water temperatures.[43]

As previously stated (Section 2.24), ambient and water temperatures were high around Menindee leading up to the fish death event, with air temperatures reaching a maximum temperature of 37°C on Thursday 16 March (mean temperature of 28°C), which is 6.2°C above average (Figure 16). Water temperature was in the mid- to high 20°Cs at the time of the fish deaths (water temperatures at Nelia Gaari Station above Lake Wetherell (Site 425060) reached above 29°C in early March 2023). Water temperature and DO have an inverse relationship whereby as temperature increases, DO decreases.[44] Along with decreasing oxygen solubility, high water temperature can cause heat stress to fish (recorded water temperature was close to lethal levels for some native fish[45] (Figure 17)) and increase algal respiration, oxygen consumption via microbial break down of organic material, and increased respiratory oxygen demand by fish and other aquatic animals.[46]

Work by Mitrovic et al. (2011) suggests that stratification of Weir 32 weir pool only occurs at flows less than about 350ML/day.[47,48] As flows into the top end of Weir 32 weir pool exceeded this threshold for the entire period of the March 2023 fish deaths, stratification is not considered a significant causal factor.

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42 Water NSW (2023). Menindee Lakes Community Update – 25 January 2023.

43 NSW Department of Planning and Environment (2023). Murray-Darling Basin – Water Quality Update – 11 January 2023 – water quality and dissolved oxygen results.

44 Atlas Scientific (2022). How Does Temperature Affect Dissolved Oxygen?

45 Baldwin, D (2023). Proximate Cause of the Fish Deaths in Weir 32 Weir Pool (Menindee) in March 2023 *(Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee)*.

46 NSW Department of Planning and Environment (2023). Murray-Darling Basin – Water Quality Update – 11 January 2023 – water quality and dissolved oxygen results.

47 Mitrovic, S.M., Oliver, R.L., Rees, C. et al. (2003). Critical Flow Velocities for the Growth and Dominance of *Anabaena circinalis* in Some Turbid Freshwater Rivers. *Freshwater Biology*, *48*(1) 164-174.

48 Mitrovic, S.M., Hardwick, L. and Dorani, F. (2011). Use of Flow Management to Mitigate Cyanobacterial Blooms in the Lower Darling River, Australia. *Journal of Plankton Research*, *33*(2) 229-241.

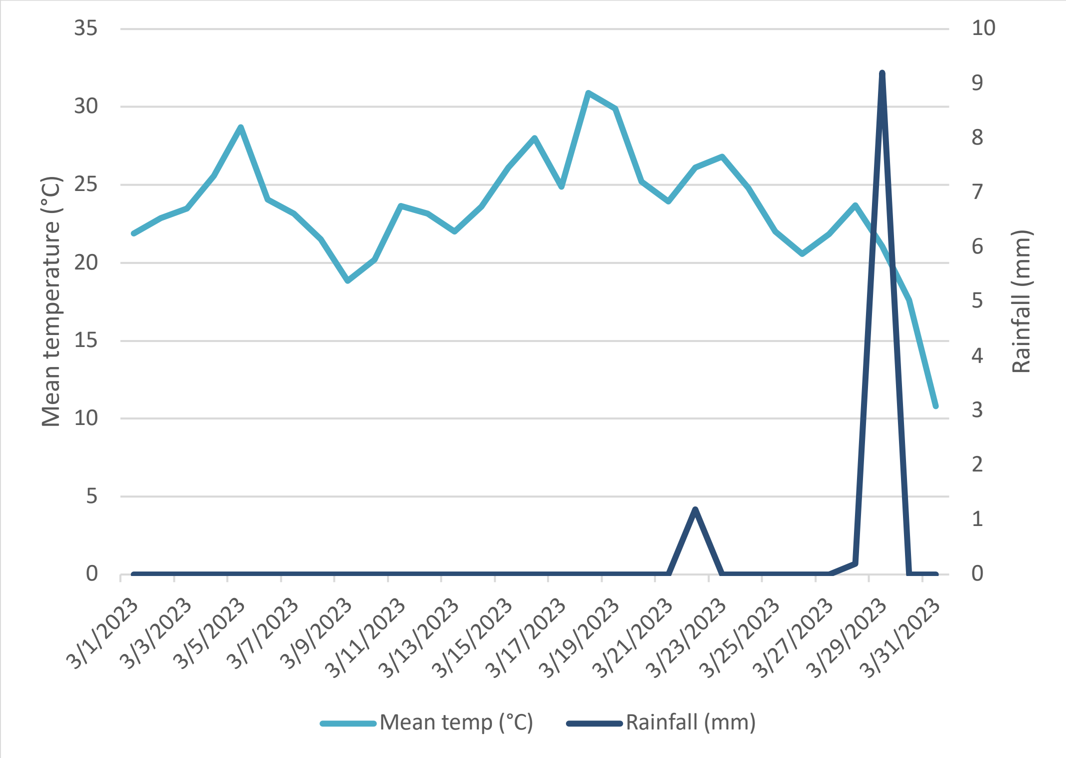

Figure 16: Mean rainfall and temperature at Menindee Post Office (station 047019). *Source data: Commonwealth Bureau of Meteorology (http://www.bom.gov.au/climate/data/).*

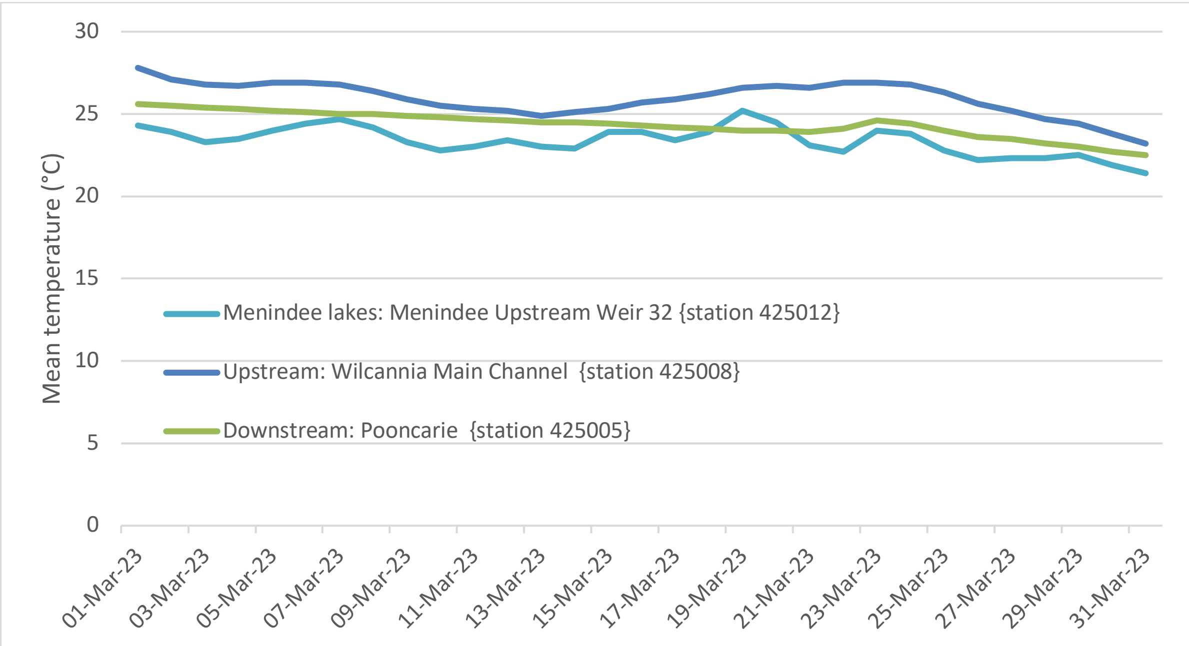

Figure 17: Water temperature at Weir 32, Wilcannia and Pooncarie. *Source data: Commonwealth Bureau of Meteorology.*

2.5 Algae and algal toxins

Algae sampling by the responsible agency (WaterNSW) in the Menindee Lakes system is both programmed and based on ad hoc requests at select sites. In the absence of algae concentrations at red alert level, WaterNSW sampling occurs monthly, as well as in response to requests from landholders and local government, or as otherwise required.[49] Algal alerts are issued by Regional Algal Coordinating Committees (RACCs) who are responsible for the local management of algal blooms.[50]

Aalgal blooms can increase oxygen levels within water during the day through photosynthesis but become nett consumers of oxygen overnight via respiration in the absence of sunlight. This can contribute to hypoxia in the early hours of the morning, and subsequently fish deaths are more likely to occur during this time. This metabolic cycle is often reflected in a diurnal pattern of dissolved oxygen peaks in monitoring data when algal biomass is present (e.g. Figure 18). Algal blooms may also contribute to low oxygen levels when microbial decomposition of dead algal cells consumes dissolved oxygen.[51]

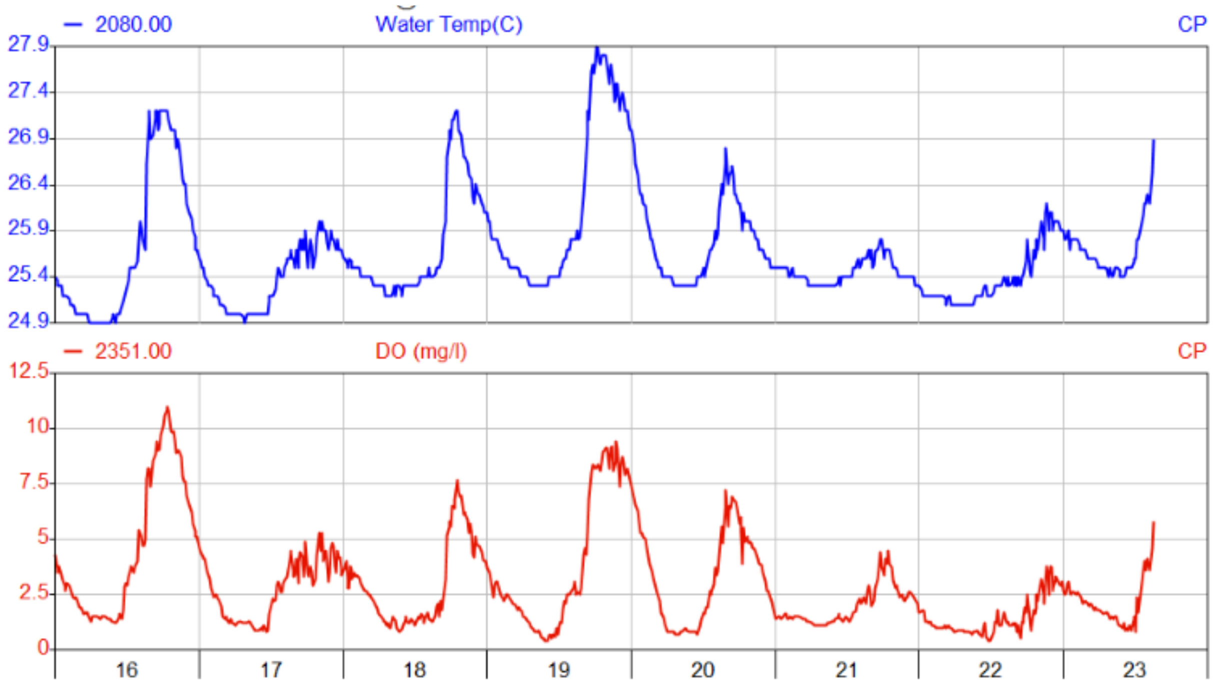

Figure 18: Continuous dissolved oxygen (mg/L) and water temperature (°C) in the Darling River at Nelia Gaari Station. Showing diurnal pattern of dissolved oxygen peaks coinciding with ioncreased temperature and sunlight during daylight hours when algal biomass is present. *Source: Water NSW.*[52]

Algal accumulation can be caused by several factors including changes in temperature, light, nutrient loads and altered water flows. The flood conditions towards the end of 2022 provided ideal conditions for the accumulation and growth of large amounts of algae, with elevated temperatures and presumed large ingress of nutrients. Localised algae production along with the high flows would have meant that total algae biomass would have been much higher than in normal conditions. Table 1 shows the results of algal testing in and around the weir pool (upstream and downstream) from February to April 2023. Further, analysis of satellite imagery by Tracey Fulford (WaterNSW) using a custom script for algae (particularly cyanobacteria, an algae-like bacteria) has shown the algal biomass increased prior to the fish death (Appendix 6). Toxins produced by cyanobacteria have the potential to impact humans, wildlife and stock if consumed.[53] However, WaterNSW testing for toxic cyanobacteria suggests this was not an issue during the March fish deaths (Table 1).

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[49] NSW Government Water (2023). Community Updates and Frequently Asked Questions.

[50] WaterNSW (2023). Algae Alerts NSW Map.

[51] NSW Department of Planning and Environment, Water Group (2023). Fish Deaths in the Darling-Baaka River – Part A (*Submission to the Independent Review into the 2023 fish deaths in the Darling-Baaka River at Menindee*).

[52] Shows the diurnal pattern of dissolved oxygen peaks coinciding with increased temperature and sunlight during daylight hours when algal blooms are present.

[53] Water Quality Australia (n.d.). Cyanobacteria (blue-green algae) and Water Quality.

As algae are primary producers, they have the potential to increase productivity of bacteria, protozoa, macroinvertebrates and ultimately, fish in the system. It is probable that this played a role in the March 2023 fish deaths, although because the deaths were largely localised at the top end of Weir 32 weir pool and not in Lake Wetherell, where there was also extensive algal biomass, algae were likely not the only factor leading to the fish deaths.[54]

The March fish deaths and their subsequent decomposition resulted in a range of water quality issues, including elevated nutrients that have likely contributed to the algal blooms in the Lower Darling-Baaka during the late Autumn and Winter months, which is an atypical period for algal blooms to occur. Algal suppressions can be addressed by triggering a flushing flow event in dry years to break up and disperse algal blooms.

Table 1. Algae and cyanobacteria biovolumes in the Darling-Baaka River system from February to April 2023. Conditional formatting represents alert level.[55] *Source data: Water NSW.*

Station Name	Date	Cyanobacterial biovolume (mm^3/L)	Algal biovolume (mm^3/L)	Toxic Cyanobacterial biovolume (mm^3/L)
Pooncarie	17-Feb-23	10.85	65.11	4.35
	23-Feb-23	6.12	36.36	3.16
	01-Mar-23	5.46	23.76	2.14
	06-Mar-23	2.85	16.49	0.30
	14-Mar-23	2.19	7.46	0.13
	03-Apr-23	0.44	4.32	0.10
Weir 32	22-Feb-23	1.87	10.51	1.19
	21-Mar-23	0.17		0.03
	28-Mar-23	0.91	2.70	0.64
	25-Apr-23	0.81	7.50	0.15
Lake Wetherell (Site 4)	21-Feb-23	5.94	27.71	1.87
	27-Mar-23	4.35	18.01	1.67
	24-Apr-23	3.59	17.84	0.54
Pamamaroo Inlet	20-Feb-23	5.21	23.73	3.58
	27-Mar-23	7.67	28.79	2.49
	25-Apr-23	1.07	15.30	0.10
Pamamaroo Outlet / Regulator	20-Feb-23	1.85	19.57	0.38
	27-Mar-23	3.93	15.10	1.32
	25-Apr-23	1.88	7.49	0.01

2.6 Post event sampling and analysis

2.6.1 Fish monitoring

DPI Fisheries has conducted fish surveys since June 2019 on the status of the fish communities in the Lower Darling-Baaka River (2019 - 2023), under a contractual agreement between the MDBA and NSW DPI Fisheries. Some surveys were postponed or missed due to poor access or high-flow/flood conditions. However, they provide an indication of the fish populations in the Lower Darling-Baaka over this time. Based on these surveys, species that benefited from the flood conditions and increased in abundance prior to the March 2023 fish deaths include common carp, bony herring, goldfish, Australian smelt, freshwater prawns and yabbies. Golden perch were reported to have benefited from flood conditions but were still well below their pre-2018 (drought) levels.

54 NSW Department of Planning and Environment, Water Group (2023). Fish Deaths in the Darling-Baaka River – Part A (*Submission to the Independent Review into the 2023 fish deaths in the Darling-Baaka River atMenindee*).
55 RACC recreational alert values; Red (5.0 to >20.0 mm3/L); Amber (0.5 to 5.0 mm3/L); Green (0.05 to 0.5 mm3/L).

In May 2023 (i.e. post the March fish deaths) surveys were conducted using standardised boat electrofishing, unbaited bait traps and 'opera house' traps at the Menindee weir pool (from Weir 32 to the Menindee Main Weir) as well as the Pooncarie Reach (river between Weir 32 and Pooncarie).These showed (when compared with previous survey periods) there were decreases in bony herring (the most affected), Murray cod, Australian smelt and freshwater prawn.

The most abundant species observed after the March 2023 event include carp, bony herring, goldfish, spangled perch and golden perch (who breed and are recruited during floods and high flows). While there were decreases in bony herring over the survey years, they were still an abundant species after the March fish death event, with more observed at the Menindee weir pool than the Pooncarie Reach, as was the case with golden perch, spangled perch and silver perch, suggesting movement upwards to the Menindee weir pool during or after the March event. Figure 19 shows the mean abundance of fish species before (June 2021) and after the March fish death event (May 2023).[56]

The number of Murray cod detected in the May 2023 survey was lower than observed over previous surveys, with low numbers throughout the 2019-23 survey period. However, the Lower Darling-Baaka Murray cod population was one of the most robust prior to 2018 and earlier fish death events. Murray cod were not recorded in the Menindee weir pool in May 2023. However, recreational fishers and the community have stated that they have observed Murray cod in that area. Due to their size, Murray cod can be more susceptible to water quality issues.

[56] Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

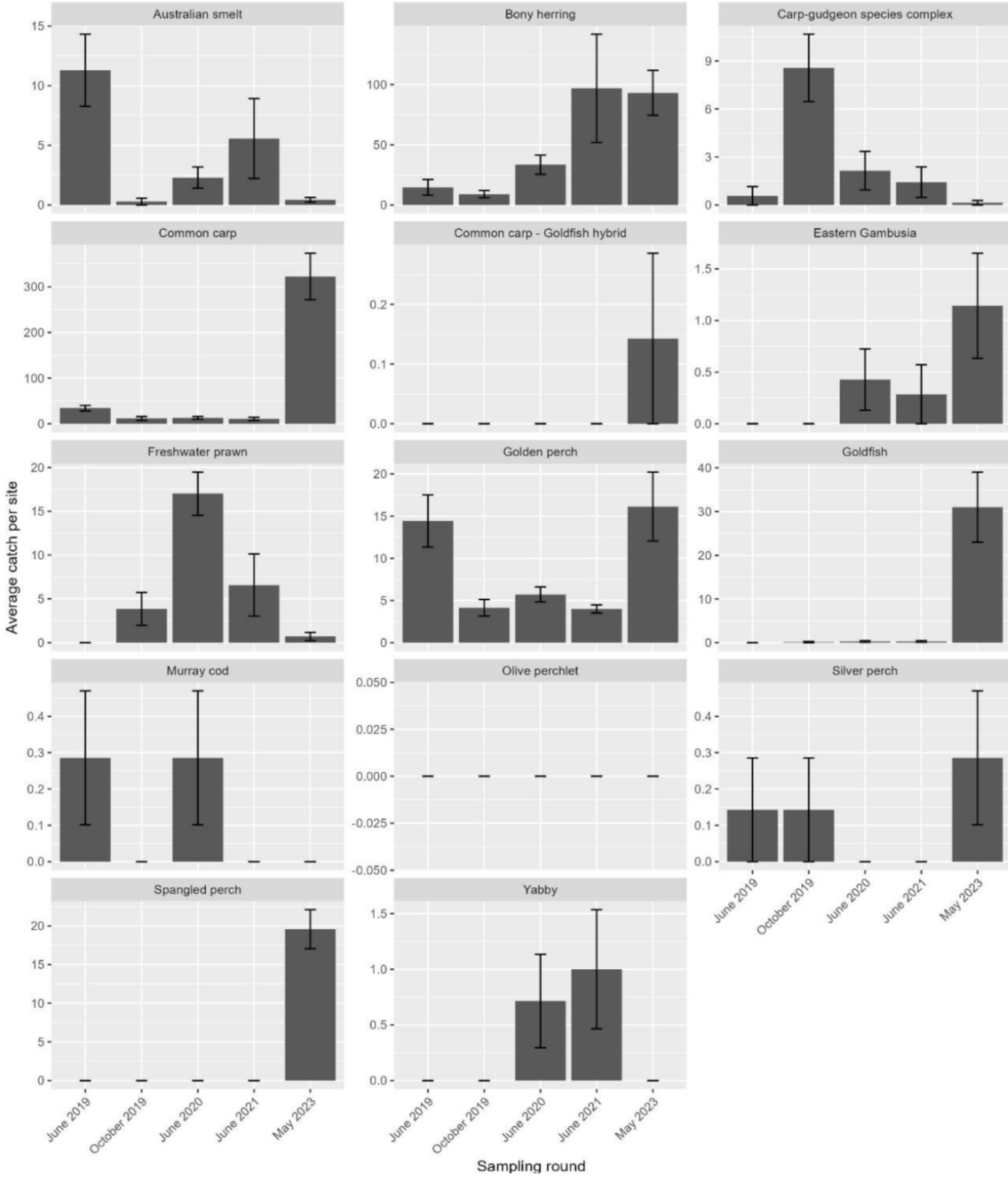

Figure 19: Mean abundances per site in the Menindee weir pool during NSW DPI Fisheries surveys. *Source: Stocks and Ellis (cit. below).*[57] (Round 1 (June 2019), Round 2 (October 2019), Round 3 (June 2020), Round 4 (June 2021, pre-flood) and Round 5 (May 2023, post fish deaths)).

57 Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

2.6.2 EPA post event sampling

In April 2023, the NSW EPA determined that it would treat the March fish death event as a 'pollution incident' under the Protection of the Environment Administration Act. Under this authority, the EPA reported it would fully investigate the potential cause/s of the mass fish deaths, whether any pollution offences were committed and if regulatory action may need to be taken following its findings.[58] Sampling was undertaken, complying with the statutory requirements.[59]

As part of this process, a pesticide pollution event was ruled out with results coming back negative for more than 600 pesticides. Samples were also tested for chlorides, alkalinity, ammonia, nitrogen, phosphorus, metals, pesticides and bacteria.[58]

EPA sampled water at various intervals from 21 March up until 18 May following the March 2023 fish death event.[60] Sampling sites differed across the sampling period but samples were generally taken in the weir pool.[61] Further sampling included downstream from Pooncarie (from 30 March). There has been criticism that water testing was not undertaken upstream, from above the fish deaths.[62] The number of samples differed across sampling dates but ranged from 5-20 samples (in the weir pool and downstream). In-field measurements included pH, dissolved oxygen, conductivity, temperature and turbidity.

2.6.3 Review-commissioned water and sediment sampling

The Review commissioned a team from the Gulbali Institute at Charles Sturt University in Albury to undertake water and sediment sampling at several locations. The aim was to seek a baseline for water and sediment quality through rapid assessment of the Menindee Lakes and Darling-Baaka system. The results of the work may help inform water and sediment quality management plans and future monitoring programs.

The methodology consisted of taking water samples at six sites in the river and lakes around Menindee , collecting from both deeper water and at the water edge at each site. The team undertook *in-situ* water measurements for turbidity, pH, temperature, salinity, specific conductivity, dissolved oxygen concentration, dissolved oxygen saturation, chlorophyll and phycocyanin (PC). Water samples were collected for lab analysis for nutrients (total nitrogen (TN), total phosphorus (TP), ammonia, nitrate, nitrite, nitrogen oxides (NOx), biological oxygen demand (BOD), chemical oxygen demand (COD), metals, herbicides and pesticides). Metals, herbicides and pesticides in water and sediment were analysed with the results compared against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) guidelines where available. The full report is in Appendix 8.

The *in-situ* analysis found overall moderate nutrient loads typical of agricultural land use nearby. All water sampling sites showed high turbidity, while nutrient levels (total phosphorus (TP) and total nitrogen (TN)) generally exceeded ANZECC water quality triggers for a slightly-moderately disturbed ecosystem. Noting that the testing was done post fish deaths, the relatively high nutrient loads may be partially due to the presence of large numbers of decomposing fish and this may have contributed to the year's unseasonal winter algal blooms in the Lower Darling-Baaka River.

NOx levels measured at the Pamamaroo Lake site slightly exceeded ANZECC trigger values for lowland rivers and freshwater lakes. Chlorophyll exceeded the ANZECC water quality triggers for slightly-moderately disturbed ecosystem at all sites, but there was a caveat on the precision of the *in-situ* monitoring equipment used for testing. Chlorophyll and dissolved oxygen levels indicated an algal bloom,

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[58] NSW Environment Protection Authority (2023). EPA Investigation into Darling-Barka Fish Kill.

[59] NSW Environment Protection Authority (2022). Approved Methods for the Sampling and Analysis of Water Pollutants in NSW.

[60] WaterNSW took a number of samples on behalf of the EPA.

[61] NSW Environment Protection Authority (2023). Menindee fish deaths follow up: Darling-Barka River water tests.

[62] The Guardian (2023), Water testing after Menindee fish kill shows a 'chronically sick' river.

and the pH range consistently exceeded ANZECC water quality trigger values for slightly-moderately disturbed ecosystem.

Metals testing found that aluminium and copper levels exceeded the ANZECC trigger values at all sites. In sediment samples, the following were detected: aluminium, barium, cobalt, chromium, copper, iron, lanthanum, manganese, nickel, lead, strontium, titanium, vanadium and zinc. Herbicides and pesticides were not found in the sediment samples. Herbicides detected in water samples included metolachlor, atrazine, simazine, terbuthylazine, tebuthiuron, clopyralid and fluroxpyr. Several of these exceeded trigger values.

2.7 Ecosystem decline in the Lower Darling-Baaka

The Darling-Baaka is ecologically significant and contains a diversity of terrestrial and aquatic flora and fauna – including both threatened and nationally important wetlands. The entire Basin is home to 16 internationally significant Ramsar wetlands, 35 endangered species and 98 species of waterbirds.[63] The Barwon-Darling, the Lakes and Lower Darling-Baaka are recognised as one of the "*most ecologically important fish movement corridors in the Basin*".[64]

The *2021 Australian State of the Environment* (SOE) report, while not focusing specifically on the Lower Darling-Baaka, points to the Murray-Darling Basin system as showing evidence of collapse.[63] The *2021 NSW State of the Environment* (NSW SOE) report illustrates similar concerns about the health of the Basin, noting that "*Murray-Darling Basin rivers are generally in poorer condition than Eyre Basin*" and its rivers are generally in poorer condition compared to coastal rivers.[65] The highly regulated nature of the Darling-Baaka has likely compromised ecosystem resilience and increased vulnerability to stresses that can cause system crashes in the absence of adaptive responses.[66] A simplified conceptual network map of the ecosystem and other influencing factors is shown in Appendix 7.

2.7.1 Altered flow regime

The flow regime in the Lower Darling-Baaka River has changed significantly since the completion and filling of the Menindee Lakes storage scheme in 1968.[67] Flows into the Lower Darling-Baaka, including through the weir pool around Menindee, are highly dependent upon storage and take from upstream Barwon-Darling and tributaries, the management of the Menindee Lakes system and climate. While varied flows are natural and beneficial in a semi-arid river system, there is strong evidence indicating that cease-to-flow and low-flow events are increasing, to the detriment of the ecological health of the system.

> *… extended periods of low- and no-flow periods place significant stress on communities and the environment, which rely on flows from the river. There has been a step change and an increase in the frequency of extended low-flow periods over the last 20 to 30 years.*[68]

Flows measured at the Wilcannia Main Channel are representative of flows into the Menindee Lakes. In addition to an overall decrease to the mean flow over from 1972 to present, the periods of low and cease-to-flow events have increased (Figure 20). The increased frequency and duration of ceased and low-flow events are expected to impact water quality. Further, native fish spawning and recruitment are affected

[63] Cresswell, I.D., Janke, T. and Johnston E.L. (2021). Australia State of the Environment 2021: Overview.

[64] NSW Department of Planning and Environment (2023). Regional Water Strategy – Western: Attachment 4: Analysis of restricting upstream licences to meet algal suppression and fish migration targets in the Barwon-Darling River.

[65] NSW Environmental Protection Authority (2021). NSW State of the Environment: River Health.

[66] Levin, S. (1998). Ecosystems and the Biosphere as Complex Adaptive Systems. *Ecosystems*, 1, 431–436.

[67] Vertessy, R., Barma, D., Baumgartner, L. et al. (2019). Independent Assessment of the 2018-19 Fish Deaths in the Lower Darling: Final Report.

[68] NSW Department of Planning, Industry and Environment (2021). Cease-to-flow and low-flow events in the Barwon Darlinf River.

by stratification of standing water, which can drive hypoxic or anoxic conditions and provide conditions conducive to algal blooms.[69]

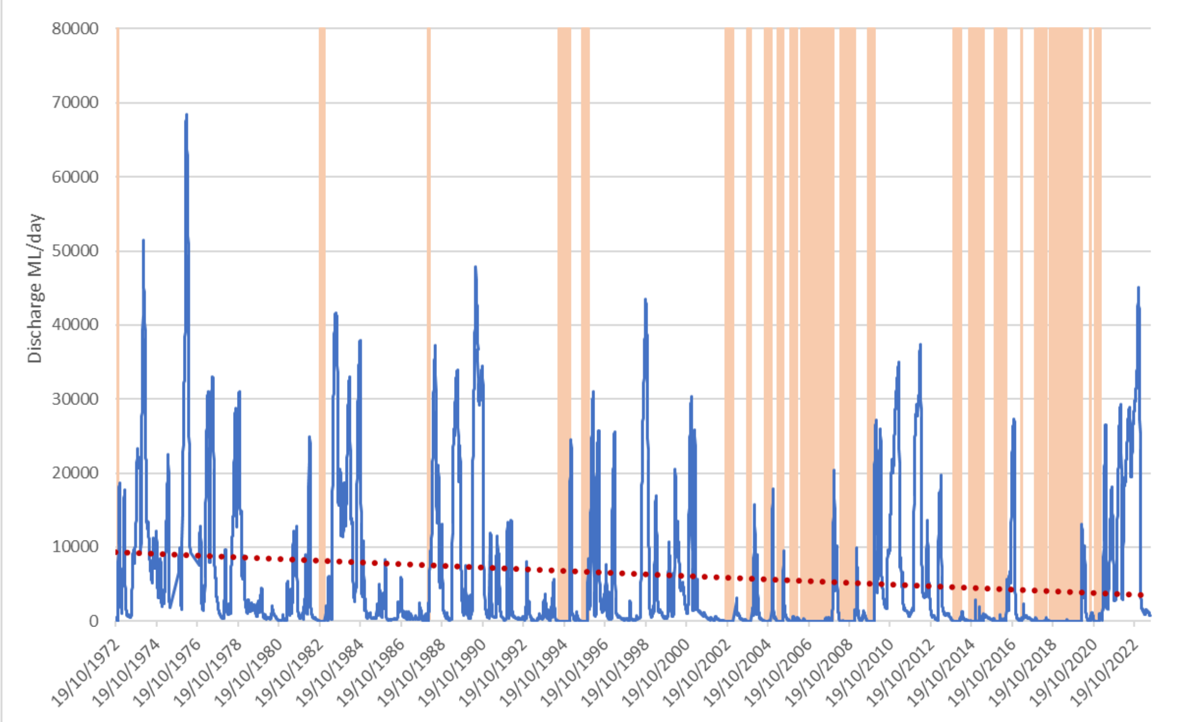

Figure 20: Historical flow (1972 to present) in the Lower Darling-Baaka River at Wilcannia (upstream of Menindee Lakes), showing mean value over time (red line) and periods of cease to flow and very low flow (<20 ML/day, orange vertical bars). *Source data: MDBA.*[70]

Analysis of historical rainfall patterns in the northern Basin do not point to declining rainfall as the likely contributor of increased low and cease-to-flow periods in the Menindee Lakes system. Work done by CSIRO (2008) for the Murray-Darling Basin Sustainable Yields Project found that mean annual rainfall in the majority of the northern half of the Basin from 1997 to 2006 was similar (<5%) or slightly higher (5-10%) than the long-term mean.[71] More recent analysis found that despite several periods of drought and natural high variability, there was little evidence of major changes in annual rainfall patterns in the tributaries or the Darling-Baaka River over the period examined (1880-2019).[72]

Accurately measuring water take from the northern Basin is challenging, particularly in unregulated river water sources.[73] The NSW Government has been working to measure and licence floodplain harvesting and on-farm storage in the northern Basin. Recent analysis of floodplain harvesting and on-farm storage from northern NSW catchments found that total on-farm storage increased from less than 600GL in 1993-4 to 1,400GL by 2019-20 (Figure 21). While work is underway to licence upstream harvesting, impacts on downstream communities and environments can be reduced by setting downstream flow targets (both volume and profile).

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[69] NSW Department of Primary Industries (2022). Fish and Flows in the Southern Murray-Darling Basin.

[70] Recorded at site 425008, Darling River at Wilcannia Main Channel. *Source:* Murray-Darling Basin Authority (n.d.) River Murray Data: Wilconnia Darling after Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

[71] Potter, N.J., Chiew, F.H.S.,. Frost, A.J. et al. (2008). Characterisation of Recent Rainfall and Runoff in the Murray-Darling Basin: A report to the Australian government from the CSIRO Murray-Darling basin sustainable yields project.

[72] Ford, Z., Jackson, S., Bino, G. et al. (2023). Scale, evidence, and community participation matter: lessons in effective and legitimate adaptive governance from decision making for Menindee Lakes in Australia's Murray-Darling Basin. *Ecology and Society, 28(1).*

[73] ABC News (2020). Flood plain harvesting and why it continues to divide Murray-Darling Basin communities and irrigators.

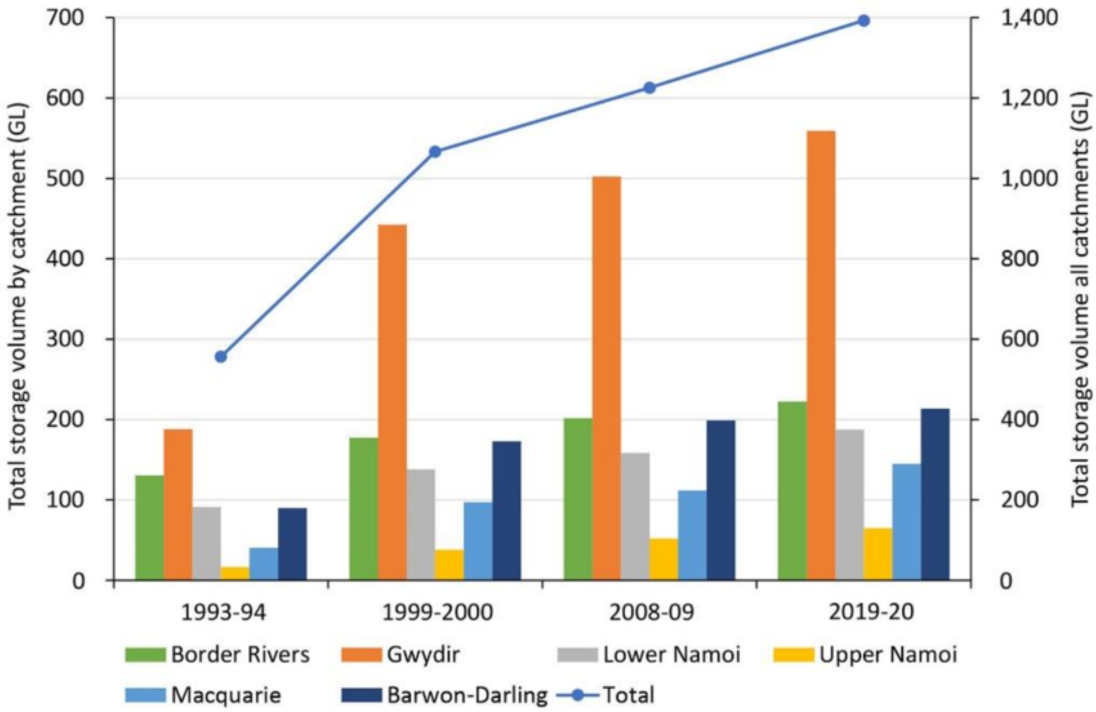

Figure 21: Growth in take by on-farm storages and floodplain harvesting in the northern Murray-Darling Basin, Australia. *Source: Cit. below.*[74]

2.7.2 Changes to components of a healthy riverine ecosystem

Further to altered flows, scientific and significant anecdotal evidence support decadal changes in key components of a healthy riverine ecosystem in the Darling-Baaka. It is important to establish a baseline understanding of how much the system is in decline, with substantial integration of Traditional Ecological Knowledge (TEK). Sheldon (2019) points to significant knowledge gaps that severely impact understanding of flow-ecology relationships.[75]

The impacts from activities in the northern catchment (e.g. agriculture, land use changes, loss of vegetation) are evident in longitudinal data sets of floodplain wetlands where excess nutrients, macrophyte loss and huge fluxes of increased sediment have occurred.[76] Evidence of increases in algal blooms, salinity spikes, cold water contamination and pesticides/herbicides have also been recognised.[77] The NSW SOE notes that greater than 75% of surface water samples collected from the Darling-Baaka River near Menindee exceeded water quality guidelines for both total nitrogen and total phosphorus.

The loss of keystone species, such as mussels, turtles and some species of fish are indicators of overall ecosystem demise. Given the importance of different types of flow events to fish biology, the altered flows seen in the Darling-Baaka River are likely to be detrimental to the long-term persistence of native fish.[75] The long-term impacts of declining water quality can directly cause mortality to adult fish, juveniles or eggs and impact environmental cues for spawning and recruitment.[75] Native fish across the Murray-Darling Basin have declined over the last 100 years. Catches of golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and large-bodied (up to 1,400 mm long) Murray cod (*Maccullochella peelii*)

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[74] Brown, P., Colloff, M., Slattery, M. et al. (2022). An Unsustainable Level of Take: On-farm storages and floodplain water harvesting in the northern Murray-Darling Basin, Australia. *Australian Journal of Water Resources* 26, 43-58.

[75] Sheldon, F. (2019). Technical Review of the Water Sharing Plan for the Barwon-Darling Unregulated and Alluvial Water Sources 2012: Advice to the NSW Natural Resources Commission.

[76] Gell, P. and Reid, M. (2014). Assessing change in floodplain wetland condition in the Murray-Darling Basin, Australia. *Anthropocene*, 8, 39-45.

[77] NSW Department of Planning, Industry and Environment (2020), The Basin Plan: Water quality technical report for Murray Lower Darling surface water resource plan area (SW8).

have declined by 51%, 94% and 96% respectively, in the mid-reaches of the Murray River over a 50-year period.[78] No mature Murray cod were recorded in the Menindee weir pool or in the 300km stretch of the lower Darling-Baaka River in May 2023. However, recreational fishers and the community have observed Murray cod in that area.

The Barwon-Darling supports several species of river mussels, including *Alathyria jacksoni*, which is highly responsive to changes in low and zero flows.[79] More frequent and extended cease-to-flow events in the Darling-Baaka have resulted in the loss of resilience of this species, as well as other benthic macroinvertebrate communities.[80] In an aim to gain more data and establish a baseline for mussels within the Darling-Baaka, a pilot study in 2022 carried out a baseline assessment of the likely location, abundance and spawning of the river mussel, *Alathyria jacksoni* in the Darling-Baaka.[79]

There have been reports of the Darling-Baaka experiencing declines of turtles, crayfish, snails and insects. The critical nature of some of these keystone species is highlighted by a recent study that found reduced scavenging from freshwater turtles may cause water quality problems following a fish death event.[81] A loss of invertebrates across the system has been reported by community members, although scientific data is required to better understand the scale and nature of these losses.

Although largely anecdotal, there have been reported geomorphic changes to the river,[82] the clarity of the water and changes in riparian vegetation, altering habitats for native fauna.

A number of aquatic pests and weeds have been identified as potential threats to the Basin.[83] Invasive pests can destroy native wetlands, harming habitats and impacting the abundance and distribution of native biota. Within the Darling-Baaka, reports of carp, goldfish, gambusia (*Gambusia affinis*) and redfin perch (*Perca fluviatilis*) have been identified as threats to the broader ecosystem.[84] Carp in particular contribute to environmental degradation through resource competition and unsettling of sediment. Weeds have also been reported as problematic within the Darling-Baaka, with concerns that hot weather will promote further growth of species such as the native Red Azolla, which has previously been reported as smothering several kilometres of river above the weir pool at Tilpa, downstream of Bourke.[85]

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[78] Baumgartner, L., Zampatti, B., Jones, M., et al. (2014). Fish Passage in the Murray-Darling Basin, Australia: Not just an upstream battle. *Ecological Management & Restoration*, 15, 28-39.

[79] McCasker, N., Ellis, I., Danaher, K. and D'Santos, P. (2022). Lower Darling-Baaka River Freshwater Mussel Pilot Study.

[80] NSW Department of Planning, Environment and Industry (2020). Barwon-Darling Long Term Water Plan Part A.

[81] Santori, C., Spencer, R.J., Thompson, M.B. et al. (2020). Scavenging by Threatened Turtles Regulates Freshwater Ecosystem Health During Fish Kills. *Scientific Reports*, 10(1).

[82] On a site visit, an Elder showed the Review team a collapsed section of the river bank in Wilcannia, possibly caused by regulated flow changes.

[83] South Australia Department of Environment and Water (n.d.) Aquatic Weeds and Pests: Coorong and Lower Lakes at Risk.

[84] Murray-Darling Basin Authority (n.d.). Fish.

[85] ABC News (2015). Darling River Smothered by 7km Stretch of Invasive Weed at Tilpa.

3. What should we do in the future?

Unfortunately, future mass fish deaths are highly likely. Lack of dissolved oxygen and hypoxia will remain the primary cause of fish deaths – induced by proximate drivers including lack of water flow, high numbers of invasive exotic fish, low water quality and resulting algal blooms. An integrated set of engineering and environmental interventions can be, and should be, developed to mitigate the impact of these drivers of low dissolved oxygen. As discussed below, these include: recirculating water, oxygenating water, better sharing of data, improved use of fish ladders and removal of invasive fish species.

However, as discussed in Section 2, mass fish deaths are also a result of a longer term decline in the health of the broader river ecosystem. This, in turn, sets the preconditions in which proximate drivers tip the river ecosystem into a low dissolved oxygen state causing mass fish deaths. The long-term decline in the health of the Darling-Baaka River must therefore also be addressed if future fish deaths are to be avoided and the overall river ecosystem is to survive and serve future communities. As discussed below, addressing this decline requires consideration of a number of key issues:

- the enforceability of current legislation on water sharing
- a much improved and open system of holistic measurement of the state of the whole Darling-Baaka River system – including flow and water quality, and future exacerbating impacts of climate change
- a renewed approach to enabling community and government agencies to work together to repair, manage and steward this most valuable of the State's natural resources.

3.1 Risks of further water quality events and fish deaths

The current situation in the Darling-Baaka around Menindee suggests further mass fish deaths are likely in the near term. Immediate actions should thus focus on implementing emergency or interim measures to maintain dissolved oxygen levels in the weir pool near Menindee through increased supply and/or decreased demand.

Dead fish carcasses from the March mass death event have likely established a feed-forward loop. Decomposition of dead fish drives biological oxygen demand and algal blooms through increased nutrient availability, both of which are amplified by increasing spring/summer temperatures. Coincident decreased inflows place further constraints on dissolved oxygen availability in the weir pool (Figure 22). Further, BOM's latest climate driver update reports El Niño and a positive Indian Ocean Dipole (IOD) for spring. With these two events coinciding, a warmer and drier spring is predicted,[86] with the positive IOD increasing the drying influence of El Niño. The seasonal climate outlook is predicting warmer and drier conditions from October to December across most of the catchment.[86]

[86] Bureau of Meteorology (2023) Climate driver update – issued 19 September 2023.

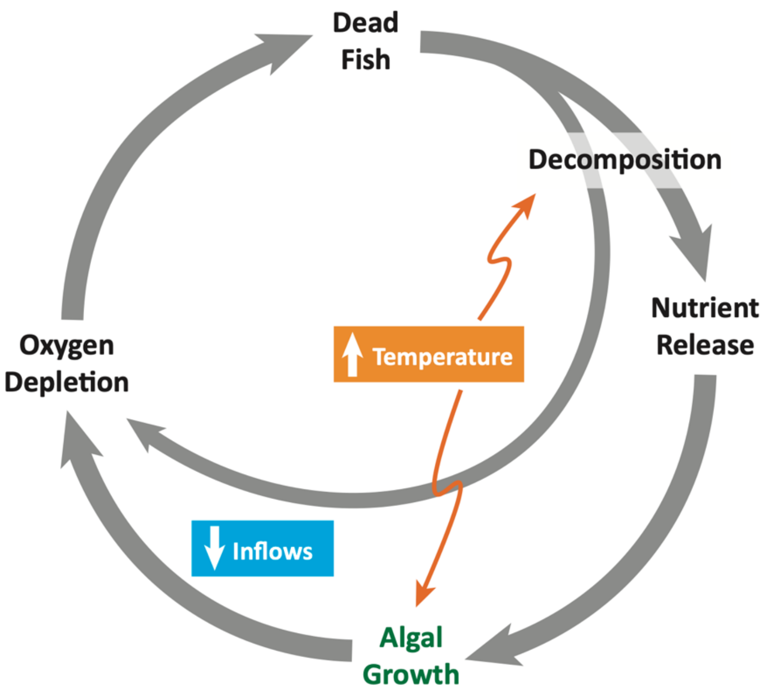

Figure 22: Fish deaths feed-forward loop. *Source: OCSE.*

Large scale fish deaths in the Lower Darling-Baaka have occurred during drought (2018-19) and flood conditions (2023). During both events, air and water temperatures were above average. Climate modelling undertaken to inform the Western Regional Water Strategy indicates that the occurrence of these climatic events and their severity is predicted to increase with climate change. The modelled dry future climate scenario (considered the 'worst case' scenario) predicts:[87]

- more hot days (an average increase of 0.7°C between 2020 to 2039 and 2.1°C in 2060 to 2079) which exacerbate risks of fish deaths
- changes in inflow patterns, most notably an increase in the times that the northern Basin tributaries do not connect with the Barwon-Darling (around 40% less median annual inflows to the Barwon-Darling)
- higher flood peaks
- greater evaporative losses.

These predicted changes could contribute to an increased risk of water quality issues, algal blooms and fish death events. The Western Regional Water Strategy highlights that the climatic conditions which led to 2018-19 mass fish deaths may occur more often.[87]

Projected climate changes may also lead to changes in the timing of fish deaths and potentially subsequent impacts associated with the decomposition of affected fish. Elevated nutrients associated with the decomposition of dead fish and other aquatic biota impacted by the large-scale fish deaths, combined with relatively mild winter temperatures, have likely contributed to the algal blooms observed in the Lower Darling-Baaka River in winter months of 2023. The red alerts issued for high levels of potentially toxic blue-green algae were not typical for that time of year.

These circumstances reinforce the need to enable fish movement between the Lower Darling-Baaka, Menindee Lakes and the northern Basin so that native fish can migrate to areas with better water quality and not be trapped in large numbers in the reach around Menindee.

[87] NSW Department of Planning and Environment (2022) Regional Water Strategy: Western.

3.2 The need for an integrated approach

Improving the resilience of native fish and other species while improving broader ecological outcomes will require integrated strategies rather than isolated actions to be effective. These include measures to concurrently ensure water flow, oxygenation and connectivity, fish recruitment and migration, and reduction of carp numbers over short, medium and longer time scales. These measures should also be considered complementary to the regulatory and governance changes discussed in Chapter 4. It is also critical that local communities and Aboriginal people are involved in the design and implementation of all measures to better protect native species as well manage invasive fish in their waterways.

Recommendation 4: Interventions to mitigate against future mass fish deaths

An integrated suite of strategies should be designed and implemented to reduce the risk of further mass fish deaths and restore the health of the broader river ecosystem. These strategies should include improved monitoring, data collection and sharing, and be integrated with other recommendations in this report. The strategies should ensure risks are identified and managed, impacts quantified and adaptive learning implemented. These interventions should at least include:

Immediate term measures (0-12 months)

Immediate measures to manage water quality should focus on maintaining dissolved oxygen in the Menindee weir pool. Potential interventions include:

- modifying the nature of environmental and other water releases (such as pulsing releases) to maximise desired benefits
- pumping/recirculation infrastructure to enable water release from Pamamaroo outlet without exhausting environmental water holdings
- investigating the feasibility of oxygenation infrastructure to maintain refugia in designated areas
- reducing oxygen demand in the Menindee weir pool by reducing biomass - including fish removal (especially carp) and suppression of algal growth
- applying short-term technical fish passage solutions to create temporary opportunities for fish to progress upstream .

Mid-term strategies (1-5 years)

- Construction of fishways identified in the NSW Fish Passage Strategy, focusing on priority Menindee Lakes sites for fishways. Priority and resourcing should be given to the construction of effective fishways to maximise fish mobility above the Menindee weir pool. Specifically, movement between Lakes Wetherell. Pamamaroo and Menindee, and the Darling River below Weir 32. These fishways should be designed in consultation with the local community, consider cultural knowledge and address the specific needs of the location.
- An integrated national invasive fish species management strategy be finalised and resourced, including physical, biological and chemical controls. Implementation of the strategy should be accompanied by an information, communication and education plan, informed by local and Aboriginal knowledge, and subject to monitoring and annual reporting of actions, impacts and adaptive management responses.
- Work with other states and territories to consider the National Carp Control Program (NCCP) and deployment of the carp virus, including how to manage the uncertainties (biomass estimates, potential for genetic resistance, herd immunity, latency and recrudescence).

Long-term strategies (ongoing)

- Restoration of flow regimes and connectivity across the catchment.
- Water quality – accounting and management of nutrient inflows across the catchment.
- Coordinated and systemic ecosystem regeneration strategies, inclusion of Aboriginal people's knowledge, including R&D and scale up of refugia for fish, invertebrate and other species.
- In addition to other performance and impact metrics, the strategy should include monitoring of iconic long-lived animal, plant and invertebrate species recognised for their contribution to river health, including species identified as culturally significant to Indigenous communities.

3.3 Maintaining near-term water quality – oxygen and flow

Dissolved oxygen in waterways can be depleted when there are significant demands in an environment, such as through high concentrations of decomposing organic matter and respiration from large populations of fish and other aquatic species. Oxygen levels can also be reduced through high levels of nutrients that can contribute to and accelerate algal growth, therefore consuming more oxygen, as well as from low water flows where sediment and nutrient build-up cannot be flushed and oxygen is not replenished.

A variety of possible interventions should be considered to manage oxygen supply and demand in the immediate term, while broader interventions are implemented over the medium-to-long term (Figure 23). Techniques, devices and structures that can be deployed to increase oxygen levels within aquatic systems (e.g. aeration and oxygenation) are already used in other sites in Australia and overseas. Some of these measures could be considered as interim solutions until fish passages are in place and could also be deployed under critical/emergency DO conditions. Adding more good quality water into the Menindee weir pool may not be sufficient to maintain oxygen levels and a combination of complementary interventions should be implemented that target the drivers of low oxygen specific to the area.

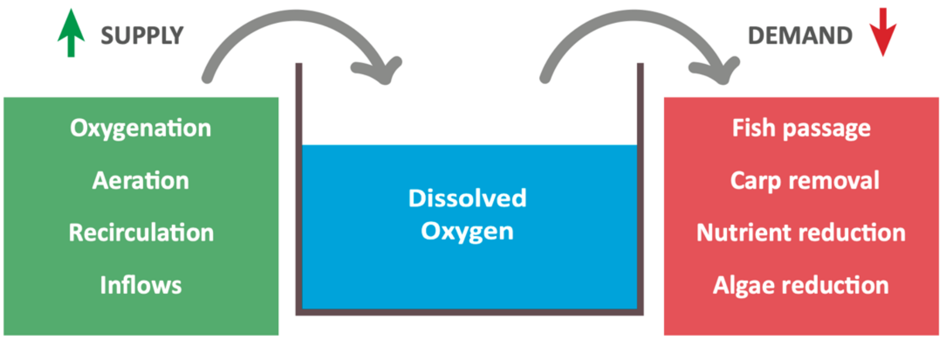

Figure 23: Potential Interventions to improve DO availability. *Source: OCSE.*

The measures discussed will not effectively address the issue in isolation and should be considered as part of an integrated solution. This includes strategies to manage invasive fish species and passages to facilitate movement of native species. Any measure implemented to increase oxygen levels should be closely monitored to evaluate changes of oxygen and other nutrients in the system and evaluate effectiveness. Importantly, in extreme scenarios or where there is an inability to oxygenate a large body of water with large-scale infrastructure, aerating refuges can maintain dissolved oxygen levels and help sustain fish populations.

3.3.1 Oxygenation

Improving water quality (specifically, DO) through side-stream oxygenation involves pumping water from a river or lake into a plant where oxygen is injected under pressure. The supersaturated water is then distributed back into the river through pipes and mixed with the existing water column through diffuser beds, increasing the overall concentration of dissolved oxygen at a reach scale.

The Western Australia (WA) Government's Swan Canning Cleanup Program[88] successfully increased dissolved oxygen levels in the Swan and Canning Rivers and reduced the occurrence of algal blooms and fish deaths in the area. It trialled a land-based plant on the Canning River and a mobile plant on the Swan River in 1998-1999.[89] Modelling that accounted for several environmental variables on each river was a key contributoir to the success of this program. Where operating the plants improved water quality and oxygen status, they became a longer term solution in both rivers. There are currently four active

[88] Jakowyna, B (2002). Swan Canning Cleanup Program: Nutrients in Tributaries of the Swan-Canning Estuarine System (1987-2000).

[89] Swan River Trust (2000).Oxygenating the Swan and Canning Rivers.

oxygenation plants near Perth (two on each river). The plants in the Canning and Swan Rivers deliver oxygen at a flow rate of 10-60kg/hr.

Operating oxygenation plant(s) in the Menindee weir pool using pipes and diffusers to target deep parts of the river or areas of known low dissolved oxygen could provide a short-term or emergency solution for improving water quality in the Lower Darling-Baaka. Menindee already has infrastructure (a water treatment plant) in place that could be utilised.

Further considerations or inclusions for plant design are:

- water volume (the length and depth of river to be oxygenated)
- plant location and numbers
- Investigation and design to determine flow rate of oxygen and water, diffuser size and position, the fluid dynamics of the receiving reach, as well as suction and pressure specific to the offtake system
- sufficient monitoring stations along the system with telemetry or remote access that can trigger turning the plant on and off, in response to oxygen levels
- ongoing operating budget that includes maintenance and considers scenarios for increased and decreased activity based on water conditions and forecasts, as well as physical impacts to infrastructure (e.g. flood and fire)
- potential negative effects of fish attraction to small sections of a well-oxygenated river.

Initial consultation with commercial suppliers and the WA Government team responsible for the oxygenation trials in the Swan and Canning Rivers suggest this approach is potentially feasible and warrants consideration. With adequate funding, appropriate design could deliver rapid and significant improvements to DO in reasonably large stretches of river, with relatively short design and installation timeframes given appropriate funding. A key difference between the Perth oxygenation plants and a potential plant in Menindee is the stagnant and low flows of the Lower Darling-Baaka compared to the Canning and Swan Rivers, which should be carefully considered.

3.3.2 Aeration

Aeration is the process of introducing air or oxygen into water through an aerator. Aerators are commonly used in water treatment systems and processes to add air or oxygen in a controlled fashion. It is one of the methods used by Sydney Water to manage sewage clean up in water bodies to minimise the risk of DO levels dropping to a point where it can trigger death of fish and other species. Aeration was also used as an emergency response to the 2018-19 fish deaths in the Lower Darling-Baaka River. This was to address hypoxia in the water column following thermal destratification[90] and to protect remaining fish populations in disconnected pools. Aeration has also been used in the Macquarie River and trialled by DPI Fisheries at its research centre.

Trials were conducted in the Darling-Baaka River during 2019 and 2020 using four types of aerators:

- high-volume, single-port Venturi aerators
- multi-port Venturi aerators
- solar-powered bubble diffusers
- ultra-fine bubble-injection pumps.[91]

In these studies, the single-port and multi-port Venturi aerators kept the pools oxygenated when they were in operation, while neighbouring pools without aerators became hypoxic. The single-port Venturi aerator was more effective at maintaining oxygen levels than the multi-port aerator, but consumed more fuel to run. The ultra-fine bubble pump increased dissolved oxygen in the pool where it was located, leading to to smaller bubbles remaining in the water column for longer, compared to pools where there

[90] Destratification occurs when there is a mixing of a large volume of oxygen-depleted bottom water with the smaller oxygenated surface layer.

[91] Baldwin, D.S., Boys, C.A., Ann-Marie Rohlfs, A-M, et al. (2021), Field trials to determine the efficacy of aerators to mitigate hypoxia in inland waterways. *Marine and Freshwater Research*, 73(2) 211-222.

was no aerator. In summary, aerators increased oxygen in pools but a careful consideration of aerator type, the volume of water to be oxygenated and access to fuel or energy sources is needed.

Diffuser aerators can disperse small bubbles into a water body, transferring oxygen from the air to the water. Diffusers can be designed as a long bar, where compressed air is emitted from small holes that release the bubbles of air/oxygen into the receiving waterbody. Diffusers are generally less effective in shallow water with a larger surface area. In the trial along the Darling River, the effectiveness of the solar-powered bubble-plume diffuser depended on power output relative to (a) the surface area and (b) depth of the pools.

Sydney Water is currently conducting aeration trials and exploring technologies, equipment and options to increase oxygen in water through diffused aeration. Once the trials are completed, Sydney Water could provide detailed advice on appropriate aeration solutions for refugia along the river.

3.3.3 Pumping/Recirculation and Flow Pulsing

Recirculating water between the Menindee weir pool and the river could be an economical and effective way to preserve oxygen levels in the water body and reduce the likelihood of fish death events. It could significantly reduce the need to use environmental water flows to maintain oxygen levels, which would be a major budgetary consideration. If found to be effective, it would preserve environmental water holdings or the EWA for low flow periods.

As the weather becomes hotter and drier, both system inflows and flows coming through the weir pool are likely to reduce. With a potential risk of fish deaths, the Review considered the feasibility of recirculating water through the Lakes as a short-term measure to improve dissolved oxygen levels in the reach at Menindee. The current practice of prioritising water from Lake Menindee over upper lakes with delivery only metered as the flow over Weir 32, means that flows often bypass the majority of the weir pool. Recirculating water from the weir pool back into the lakes and releasing relatively well oxygenated water from the upper outlets would allow higher flow velocities through the weir pool without exhausting water holdings. Aeration during pumping, dilution into large volumes and increased exchange rates in shallow lakes would also help reoxygenate depleted water.

Preliminary discussions with experienced stakeholders led the Review to conclude that pumping is a feasible short-term option to improve water quality in the weir pool. Detailed scoping, design, costing and implementation could be feasibly achieved in 4-6 weeks. There are precedents for this type of response that can offer insight.

Based on experimental analysis, around 727ML/day may be needed to limit stratification of the Menindee weir pool.[92] This is the estimated volume required to maintain a flow velocity above 0.05m/s. Under current operating rules, WaterNSW is required to deliver 350ML/day from January to March, 300ML/day in April and 200ML/day from May until December, all metered over Weir 32. These figures are well below the suggested flows required to improve water quality in the weir pool.[93]

Two routes to pump water could be considered and/or used alternatively as conditions allow:

- in two stages, from the Lower Darling near the confluence of Menindee Creek to Lake Menindee (ie near Menindee outlet regulator), then via the Menindee inlet regulator to Copi Hollow and into Lake Pamamaroo

[92] (Recommended discharge of 727ML/day at Menindee Old Town Weir and 909ML/day with 25% leeway to reduce stratification that can lead to algal blooms and fish deaths. The authors acknowledged that further data collection is needed on stratification in the weir pools to understand the flow thresholds. Refer to article for additional suggested further work.) *Source: Facey, J., Balzer, M., Brooks., et al. (2021). Minimising Persistent Thermal Stratification and Algal Blooms using improved Flow Velocity and discharge targets. Taskforce MER Plan: Project 08.5 Report*.

[93] These minimum flows which are required under Clause 18 of the Murray and Lower Darling Water Supply Works Approval are intended to maintain water quality and river health and minimise the occurrence of algal blooms. They are described in the operational guidelines for delivering flows prescribed by the Murray Darling Basin Agreement.

- from the existing water treatment plant pump house near the railroad bridge using the decommissioned Broken Hill pipeline to Copi Hollow and into Lake Pamamaroo.

Existing power infrastructure is available at the Menindee water treatment plant but feasible renewable energy options exist (e.g. solar farm) that could provide power to run pumps during daylight hours. WaterNSW can advise about the existing pumping infrastructure, both fixed and portable. The project team will need to consult with the EPA regarding any licencing issues.

When tested with stakeholders, concerns were raised about the risk of circulating low-quality water into the lakes and river, including nutrients from decomposing fish in the weir pool. This will need to be considered more closely by the technical group, but the consensus was the high dilution factor in the lakes would overcome this. Some algal blooms are inevitable at this time of year in the system regardless.

Recirculating water by pumping might also help address, even in part, the (unsustainable) and expensive use of environmental water to manage water quality in the Menindee weir pool. In terms of water accounting, as the water would remain in a circular loop without flowing over Weir 32, it wouldn't be counted against environmental water holdings or the EWA and could be used during times of low storage volumes.

Multiple groups have also called for trialling and testing pulsing flows in the weir pool, noting that pulsed high flows interspersed with periods of lower flow may be more beneficial than a consistent flow in mitigating the cause of fish deaths.[94,95]

3.4 Fish management strategies – native and invasive fish species

To mitigate or avoid future fish deaths events, research and submissions identified several actions that should be considered to improve the overall resilience in the system. These include programs to improve fish migration, increasing the number of fishways and their efficacy (for native species), installing fish screens on irrigation pumps, and reducing the number of invasive fish such as carp through harvesting or biological control. In combination, these actions would reduce high biological oxygen demand, particularly between Weir 32 and Main Weir, improve other aspects of water quality and restore habitats for other species.

3.4.1 Fish passages and programs to improve fish migration and native fish outcomes

Fish need unrestricted movement upstream and downstream and into connected water bodies to breed, spawn, find food and avoid threats. Dams, weirs and other physical infrastructure have largely blocked fish migration and as a result the abundance of native fish species throughout the Darling-Baaka River has decreased over time. To address this, fish passages have either been constructed or recommended for parts of the river. The need for adequate passage was highlighted by the Murray-Darling Basin Native Fish Strategy and the NSW Fish Passage Strategy. Fish passage structures come in many forms and their effectiveness is determined by the surrounding environment, the rate of water flow, the fish to be targeted, the ability to support bidirectional movement and the height to be traversed. It is important to note that the best way to remediate a barrier is to remove it altogether.

Modern fishways have largely been built based on refined northern hemisphere designs which have been adapted to Australian conditions. Common types of fish passages include Denil, rock ramp, vertical slot, pool and weir, and mechanical fishways such as locks or lifts.[96] Twelve submissions to the Review included recommendations relating to the need for funding to achieve the NSW Fish Passage Strategy, the need for improved fish passage between the Menindee Lakes and addressing fish passage at Weir 32. Historically, stone, wood and earthen fish traps and fish weirs were designed and built by the Barkandji people to enhance and manage water in the area that contributed significant knowledge about the flows

[94] Commonwealth Environmental Water Holder per comms 11 Aug 2023.

[95] Facey, J., Balzer, M., Brooks., et al. (2021). Minimising Persistent Thermal Stratification and Algal Blooms using Improved Flow Velocity and discharge targets. Taskforce MER Plan: Project 08.5 Report.

[96] NSW Department of Primary Industries (n.d.). Fishways.

of the system. There are still the remains of stone fish traps within the Darling-Baaka River, and these are spiritually and culturally significant to Traditional Owners.[97,98]

> *"DPI Fisheries stress the importance of achieving catchment scale connectivity through the remediation of all priority barriers within a waterway. The persistence of a single barrier … can significantly impact the ecological gains achieved through fish passage remediation at adjacent weirs."* [99]

The Barwon-Darling, Menindee Lakes and Lower Darling-Baaka are spiritually and culturally significant areas that are recognised as ecologically important fish movement corridors in the Murray-Darling Basin.[100] The Menindee Main Weir is a major barrier to migration in this key stretch of the entire system. Native fish migration in the Murray-Darling involves many different life-history stages. Adult golden perch, silver perch, Murray cod and bony herring move upstream and downstream in spring and summer in response to rising flow. Immature golden perch and silver perch migrate into early autumn. For some species, these movements are cyclic, with return movements occurring later in the same migratory season. Developing mitigation strategies for fish that move across large spatial scales, with many species and size classes, is a substantial challenge for river managers.

The NSW Government established the NSW Ministerial Task Force on Fish Passage (the Taskforce) in 2017, which went on to develop the *NSW Fish Passage Strategy* (unpublished at time of writing). It is a 20-year plan to restore unimpeded fish access to mainstem rivers and key off-channel habitats at priority sites below all major storage dams. It includes four programs targeted across NSW. *Program 1 – Menindee Lakes and Lower Darling* comprises seven priority fish passage sites. Menindee Lakes sites are considered the highest priority for remediation of barriers to fish passage under the NSW Fish Passage Strategy.[101] Installing fishways at key Menindee Lakes sites would support ecologically significant breeding grounds and help to re-connect the northern and southern Basin via Menindee Lakes.[101] Fish passage at this site would also likely lower the risk of further mass fish deaths at Menidee by reducing the build-up of large numbers of fish in this reach of the river.

Several programs seek to improve outcomes for native fish in the northern Basin and Lower Darling-Baaka, including through remediation of barriers to fish passage (see Figure 24). These programs are at different stages and have been designed to deliver a range of outcomes.

They include:

- **Northern Basin Toolkit** includes a range of environmental works and measures identified in the Northern Basin Review and includes the Fish Passage: Reconnecting the Northern Basin program. This fish passage program aims to create migration paths across more than 2,000 kilometres of waterways by addressing barriers to fish passage at priority sites upstream of the Menindee main levee.[102]
- **Better Baaka Program** proposes a range of initiatives including: [103]
    - Menindee Weir Modifications initiative to improve fish passage along the lower Darling-Baaka by constructing a new fishway at Lake Wetherell, constructing gates and upgrading the fishway at Weir 32 and potentially raising the height of Weir 32 for complementary operation of the

[97] The Conversation (2022). Aboriginal People have Spent Centuries Building in the Darling River. Now there are plans to demolish these important structures.

[98] Martin, S., Chanson, H., Bates, B., et al. (2022). Indigenous Fish Traps and Fish Weirs on the Darling (Baaka) River, South-eastern Australia, and their Influence on the Ecology and Morphology of the River and Floodplains. *Archaeology in Oceania*,58, (1), 91-114.

[99] NSW Department of Primary Industries, Fisheries pers comm 16 Aug 2023.

[100] Commonwealth Environmental Water Office (2021). Commonwealth Environmental Water Office Water Management Plan 2021-22.

[101] NSW Department of Primary Industries (2019) NSW Fish Passage Strategy. Unpublished.

[102] Department of Climate Change, Energy, the Environment and Water (2023). Northern Basin Toolkit.

[103] NSW Government, Water (n.d.) Better Baaka Program.

Menindee Lakes System. This initiative is not currently funded and does not include fish passage through Lake Pamamaroo, which is critical for native fish, particularly if water quality in Lake Wetherell is poor. Fish passage at Lake Pamamaroo outlet and the Lake Pamamaroo inlet are important to complete the connection to the Darling-Baaka River.

- Weir renewals on the Darling-Baaka that would deliver improved town water security and fish passage facilities.

- **Lower Darling Fish Passage Program** committed $6 million from the Commonwealth to restore fish passage connectivity along the Lower Darling-Baaka River by refurbishing existing fishways at Weir 32, Pooncarie Weir and Burtundy Weir. However, the Weir 32 fishway upgrade was moved from this program to the Better Baaka program.[104]

Not all initiatives under these programs are currently funded and there does not appear to be adequate flexibility across programs to ensure investment is targeted to addressing key issues, with key sites critical for providing fish passage through the Menindee Lakes and between the northern and southern Basin currently lacking funding. In 2019, in response to the interim report on the 2018-19 fish deaths in the Lower Darling, the Commonwealth Government committed to an accelerated program for fishways including sites at Menindee Lakes.[105] However, at the time of writing, very little progress has been made regarding fishways at Menindee Lakes.

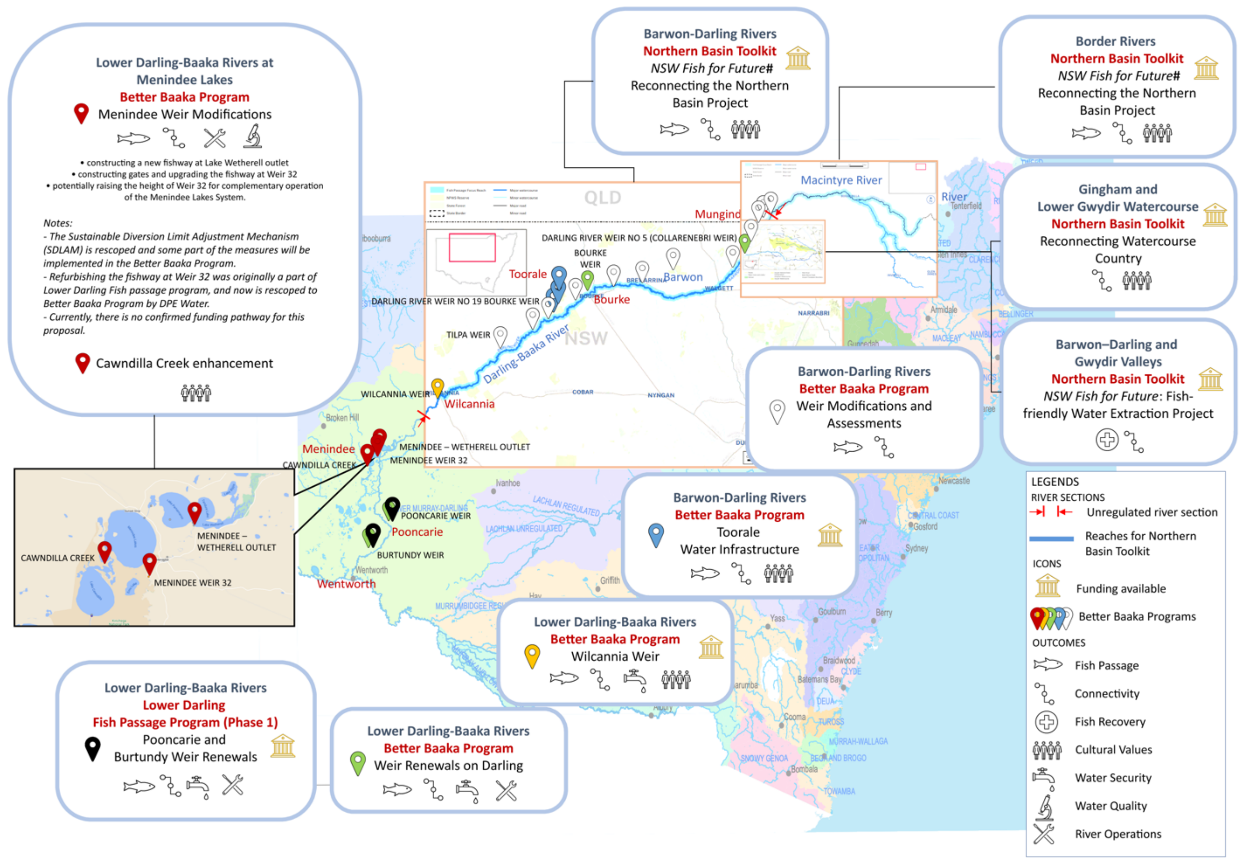

Figure 24: Existing initiatives that can contribute towards improved outcomes for native fish. *Source: OCSE.*

3.4.2 Short, medium and long-term fish passage solutions – recommended actions

Fish passage through Lakes Wetherell and Pamamaroo remain a high priority in the Lower-Mid Darling-Baaka system, as previously recommended by DPI Fisheries in the NSW Fish Passage Strategy and further

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[104] NSW Department of Primary Industries (n.d.) Vertessy Report Recommendation – Fish Deaths: DPI Fisheries Response.

[105] The National Tribune (2019). Interim Independent Assessment of Fish Deaths Release.

emphasised in its submission to this Review. At time of writing, under normal circumstances,[106] fish can only migrate upstream as far as Lake Pamamaroo and Menindee Main Weir, ending their journey in the reach where the recent fish deaths occurred. This situation is likely contributing to an increase in fish biomass within this reach. Without accelerating the installation of fishways at high priority Menindee Lakes sites and decoupling the sites at Menindee Lakes from existing programs that have experienced delays, the consequences will be significant, and further large-scale fish deaths in Weir 32 weir pool become more likely. There is currently a small-scale pilot by WaterNSW and DPI Fisheries to trial a temporary solution at the Pamamaroo inlet.[107] But this will not address issues downstream of the Main Weir system.

The following suggested actions, ideally implemented in combination, are designed to mitigate these consequences. Deep knowledge and understanding from Traditional Owners of waterflows, species and the surrounding should have significant input to the design, implementation and operation of any solutions.

Fish passage options should be considered as part of an integrated package of works and actions to protect native fish. Simply providing fish passage will not be enough to ensure long term viability of fish in the Darling-Baaka River. Complementary actions are also important including:

- modern fish screens to protect native fish from being entrained into irrigation systems
- re-snagging and river restoration to protect and enhance fish habitat
- provision of good quality environmental water to provide more natural cues for migration
- managing pollution ingress.

Recommendation 4.1: Short, medium and long-term fish passage solutions are implemented

Immediate actions (0-12 months)

- Install temporary fish passage solutions that can be rapidly retrofitted to the site. Temporary fish passages from Finland and a recently prototyped new tube design show promise, but are presently untested in Australian conditions. Any immediate measure considered would need to be installed by December 2023. This would require rapid scoping and design, and assurances that installation could be progressed provided funding and approvals were rapidly secured, as an experimental pilot. Ideally, a comparative trial of both designs would be implemented and rigorously assessed in the coming season to determine whether their long-term deployment would represent effective mitigation measures.

- Design and implement a “trap and transport” program in partnership with local communities and/or indigenous ranger groups. Trap and transport systems involve the physical capture and relocation of fish over a barrier. In early 2019, DPI Fisheries trapped and relocated 20 stressed Murray cod from a pool downstream of Weir 32. At Menindee this would require the regular movement of fish “accumulating” downstream of Pamamaroo outlet or Menindee Main Weir and release into upstream sections. It would require an investment of resources and training to ensure fish safety and minimise stress during handling.

- Monitor water quality and subsequently close fish passages at Burtundy, Pooncarie and Weir 32 at low levels of dissolved oxygen. The closure of these fish passages would prevent the further concentration of fish into the impacted zone.

- Accelerate and implement modifications to existing Burtundy, Pooncarie and Weir 32 fishways. Both the MDB Native Fish Strategy and the NSW Fish Passage strategy note that existing fish passage solutions at Burtundy, Pooncarie and Weir 32 are sub-optimal designs that require

[106] Unless the Main Weir is open at a time of flood.

[107] Finterest (2023), Making the Connection: Providing Temporary Fish Passage at the Menindee Lakes.

modifications to improve operations over a wider range of flows. Further, these designs do not take into account Traditional Aboriginal knowledge or cultural considerations.

- Publicly release results of the temporary fish passage pilot at Pamamaroo inlet.
- Develop a detailed, stand-alone business case for fishways at Menindee Lakes and at the high priority sites, to enable funding to be considered separate to broader works or larger programs that are often beset by implementation delays

Mid-term actions (1-2 years)

Investigate (through detailed engineering designs) permanent fish passage solutions for the Pamamaroo outlet and inlet and the Menindee Main Weir/Wetherell outlet:

- Lake Pamamaroo outlet and inlet: this solution would allow fish to migrate upstream into Lake Pamamaroo and downstream, to complete the connection to the Darling-Baaka.
- Menindee main weir: This site is problematic as it serves to act as an overflow weir and does not constantly release water under current operating rules. Provision of passage at this location would require an operational rule change to facilitate flows more frequently. As this site also contains sluice gates, which are harmful to fish, the installation of an overflow LayFlat gate would be required to provide adequate upstream and downstream pathways.

Long-term actions (3-5 years)

- Implement a long-term program with local communities and indigenous groups. This would integrate and operationalise the suite of solutions needed to protect fish passage, and water quality, in the Darling-Baaka. Reconnecting the Darling-Baaka will require a long-term commitment, funding and detailed works program. Annual checks should be performed to ensure all implemented solutions are operating efficiently and appropriately and that there are positive changes to fish communities throughout the Lower-mid Darling-Baaka system.

3.4.3 Invasive species control

Management of invasive species, such as the common carp (*Cyprinus carpio*), is of critical importance. Carp is an invasive species in many countries, including Australia, and it dominates most Murray-Darling Basin waterways, making up approximately 90% of fish biomass in some areas.[108] Negative impacts of carp include reducing native fish populations and increasing resource competition, uprooting aquatic plants, erosion of riverbanks, reducing water quality and clarity, and disruption of nutrient levels in water systems.[109,110]. The latest DPI survey data indicates huge numbers of carp in the Darling-Baaka River at Menindee.[111] A number of options exist for reducing carp numbers and should be considered with some urgency.

[108] McColl, K. A., and Sunarto, A. (2020). Biocontrol of the Common Carp (*Cyprinus carpio*) in Australia: A Review and Future Directions. *Fishes*, 5(17).

[109] Fisheries Research and Development Corporation, National Carp Control Plan, 2022.

[110] NSW Department of Primary Industries. (n.d.). General information about carp.

[111] Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

Harvesting

Carp can be removed from waterways by recreational or commercial fishers, and by trapping, meshing or netting. Harvesting can be effective at localised areas where large biomasses are observed, or at breeding sites, however it is resource-intensive. Carp are very efficient breeders, which can lead to sharp returns to previous population numbers. Eradication has been demonstrated to be effective in isolated water systems such as lakes but this requires a significant commitment and resources over long time periods. For example, in June 2023, the Tasmanian Government called its 28-year harvesting program a success due to the verified removal of carp from Lakes Crescent and Sorrell.[112] Bounty schemes have been used globally to control pests and in Australia, for controlling pest numbers of goats, pigs and foxes, but overall were found to be costly and ineffective at driving down numbers long term.[113] The NSW Government implemented the Carp Production Incentive Scheme between 1999 and 2001 to expand commercial carp fishing and reduce numbers, however there was limited demand and carp value was low, impacting the scheme's long-term effectiveness.[114] While bounties may not be successful at widespread control of carp, they may have a role in emergency situations to remove carp numbers in localised, high-density areas to protect water quality and other fish species, and can provide a source of income and engagement for local and Aboriginal communities.

Genetic control

Genetic technologies have been explored as a way to reduce the carp population, by producing male-only populations (daughterless technology) to limit the breeding of carp, which was first investigated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in 1995 but has not been deployed. While scientifically plausible to reduce carp numbers, further work is needed to determine its effectiveness and safety, as well as social uptake of genetic modification.[115]

Biological (carp virus)

As a way to reduce the number of carp in the system, there has been a focus on the deployment of a virus that is highly selective to carp and effective at reducing carp numbers, if managed and implemented appropriately – the herpesvirus 3 / carp virus (CyHV-3)) also known as Koi Herpesvirus Disease (KHV). See Appendix 9 for a detailed description. It is widely distributed around the world and present in over 33 countries. It has not been deliberately deployed as a biological control agent,[116] and is not present in Australia and New Zealand.

The National Carp Control Plan (NCCP) investigated the feasibility of the carp virus as a biological control agent for carp in Australia. The NCCP is summarised at Appendix 9. The NCCP concludes that the carp virus could be used as a biocontrol agent to reduce carp populations and should be considered further by states and territories. To support its efficacy, additional factors are crucial:

- **Integrated reduction strategy:** On its own, the virus is unlikely to reduce the carp population, and the use of other methods to reduce numbers would be necessary, particularly in areas with very high carp densities (approximately 2000kg/ha). This includes removing live carp from waterbodies before deployment, using using a variety of methods. The NCCP highlights the removal of carp prior to virus deployment as most important in order to reduce the effect of a large body of carp carcasses on the environment.

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[112] Tasmanian Government (2023). Jeremy Rockliff, Permier of Tasmania: Jo Palmer, Minister for Primary Industries and Water – Removing Invasive Carp from Tasmanian Waters.

[113] Koehn, J., Brumley, A. and Gehrke. (2000). Managing the Impacts of Carp.

[114] Graham, K.J., Lowry, M.B. and Walford, T.R. (2005). Carp in NSW: Assessment of Distribution, Fishery and Fishing Methods.

[115] Hayes, K. R., Leung, B., Thresher, R., et al. (2014). Meeting the challenge of quantitative risk assessment for genetic control techniques: a framework and some methods applied to the common carp (*Cyprinus carpio*) in Australia. *Biological Invasions*, 16, 1273–1288.

[116] Fisheries Research and Development Corporation, National Carp Control Plan, 2022.

- **Targeted deployment sites:** Deploying the virus in areas where there are large numbers of carp, particularly juvenile carp, can lead to higher mortality rates by facilitating close and controlled direct physical contact between carp.
- **Spring-early summer deployment:** The water temperature in these seasons will be most conducive to replication of the virus within carp once they are infected. The virus is temperature-dependent and clinical signs and mortality can be observed when water temperatures are between 18-28°C. Little or no disease is observed in temperatures outside of this range.[117]

There are some uncertainties around the longer-term suppression of carp populations using the carp virus and therefore its efficacy. Research into carp populations is continuing and is essential to a better understanding of the most effective ways to reduce carp numbers.

These include (and are further described at Appendix 9):[116,118]

- **Biomass estimates:** Accurate modelling and predictions about the population and distribution of carp throughout Australia can aid the prediction of suppression rates over time. Inputs to this modelling include river flow, water temperature, waterway inundation and connectivity.
- **Genetic resistance:** Given that carp-goldfish hybrids may be less susceptible to the disease than common carp, it is uncertain whether they may have a selective advantage, potentially leading to decreased numbers of common carp but increased numbers of carp-goldfish hybrids over time. Further, investigation into alleles that may enable genetic resistance to the virus is needed to exclude the likelihood of genetic resistance based on the genetic makeup of carp populations.
- **Herd immunity:** Carp populations could develop herd immunity to the virus, reducing the mortality rates and effectiveness of the virus.
- **Latency:** If the virus can infect fish and become reactivated at optimal temperatures or under stress conditions, then there is a higher likelihood of reducing carp numbers in the years following virus deployment.
- **Recrudescence:** The virus may lie dormant within the carp once infected but become re-activated under stress conditions. If this occurs, there are likely to be initial mortalities of carp in the first 1-2 years post-deployment, but not in the years beyond.

Further discussion of the potential benefits and risks of virus deployment should be discussed by all governments. Major considerations are whether deployment of the carp virus will deliver effective or safe biocontrol in the short and longer term, its cost-effectiveness (alone and in combination with other carp management strategies), and community sentiment around virus use.

To mitigate or avoid future fish deaths events, research and submissions identified several actions that should be considered to improve the overall resilience in the system. These centred on programs to improve fish migration, increasing the number of fishways and their efficacy (native) and reducing the number of invasive fish such as carp through harvesting and introducing the carp virus.

3.5 Better data for decision-making

Future informed decision-making to predict and respond to fish deaths must be grounded in reliable data to ensure timely identification of potential event triggers and post-event analysis. Robust data collection and analysis can shed light on the causes, extent and frequency of fish death events. It also provides a framework for developing appropriate predictive methods that identify periods of increased risk. However such data frameworks must establish consistent, efficient, whole-of-system data collection methodologies to ensure data is accurate, reliable and complete.

Components for improvement include addressing gaps in existing monitoring programs and a state-wide approach to water quality. These must be underpinned by steps to improve data quality, availability and

[117] Ronen, A., Perelberg, A., Julia, A., et al. (2003). Efficient vaccine against the virus causing a lethal disease in cultured *Cyprinus carpio*. *Vaccine*, 21(32), 4677-84.

[118] Boutier, M., Donohoe, O., Kopf, R.K. et al.(2019). Biocontrol of Carp: The Australian Plan Does Not Stand Up to a Rational Analysis of Safety and Efficacy. Frontiers in Microbiology, 10 (882).

predictive capacity. Some actions proposed here were also recommended by previous fish death event reports and reviews.[119]

3.5.1 A water quality strategy and program

A NSW (state-wide) water quality and monitoring strategy should be developed and implemented within 12 months to support data-driven decision-making. The strategy should be publicly available and updated regularly, with quarterly progress reports.

The strategy should include identification of primary quality datasets and minimum standards for all water quality monitoring programs. Quality and volumetric data sets should be managed as whole-of-government assets, irrespective of source, and be publicly available through an established federated portal (e.g. SEED).[120] A state-wide strategy should facilitate a consolidated NSW monitoring and sampling regime, providing efficiencies as well as addressing strategic needs, in both the short- (early warning) and longer term (systems and risk management).[121,122]

The strategy should provide a cross-agency emergency monitoring and sampling protocol to be activated pre-event in response to identified triggers signalling a risk of recurrence.[123] In turn, strategy outcomes and products should be directly linked to and inform actions and accountabilities for response. The protocol should be maintained during the acute phase of a mass fish death event and transition to a recovery-phase protocol. Raw data should be made available in a timely fashion on publicly accessible portals to facilitate adaptive learning and to engender community trust.

Finally, the strategy should incorporate and triangulate established and emerging technologies to capture data at different scales and locations. This includes, for example, using telemetry, satellite imagery and aquatic and airborne UAVs (drones). The cost-benefit of fixed infrastructure (gauging) and other technologies (e.g. high resolution and/or adaptive monitoring equipment) should be assessed, considering the loss and damage of water gauges along the Darling-Baaka River during flood events.

At a minimum, key knowledge gaps in existing water monitoring programs identified in this Review that should be addressed through the strategy include:

- **Water flows** – although there are good data at various points along the Darling-Baaka River, information about velocity patterns as well as volumes is needed across the Menindee weir pool (currently limited to discharge at Weir 32). These data should be linked or able to be linked to other data, for example historical events and hydrological conditions, climate models extractions and impacts of different flow regimes for species development and breeding requirements.
- **Metered releases** – at specific sites (e.g. outlet regulators).
- **Dissolved oxygen** – there is an established network of 34 continuous monitoring sites with DO sensors in the Murray, Murrumbidgee, Lachlan and Barwon-Darling.[124] Recordings taken upstream of Menindee Lakes and at Weir 32 indicated hypoxic conditions were present in the lead up to and

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[119] For example, the 2018-19 fish deaths review recommended the need to address gaps in water quality monitoring at high risks sites and to improve the use of real-time data to help better forecast and detect potential water quality events that could lead to fish deaths. *Source: Vertessy, R., Barma, D., Baumgartner, L. et al (2019). Independent Assessment of the 2018-19 Fish Deaths in the Lower Darling: Final Report.*

[120] SEED is the NSW Government's central resource for Sharing and Enabling Environmental Data. It was developed for the NSW community in a collaborative effort between Government agencies to provide an accessible and reliable platform for environmental data. *Source: NSW Government (n.d.). SEED: The Central Resource for Sharing and Enabling Data in NSW.*

[121] It is recognised that monitoring and sampling is undertaken for a range of purposes. However, the Review observed sampling undertaken by different agencies in different assets within close proximity of each other.

[122] On 26 September 2023 the NSW EPA announced $5 million would be made available for water quality monitoring in the Darling Baaka under the disaster recovery program as part of the response to the 2023 fish deaths.

[123] The protocol should encompass sampling sizes, locations of water and species samples to be taken as well as sample type e.g. toxicology of fish and other species.

[124] This includes DO sensors at hydrometric gauge sites at Moorabin (Wilcannia) upstream of Lake Wetherell and Burtundy along the Lower Darling-Baaka. Dissolved oxygen sensors were also installed at Nelia Gaari (Lake Wetherell) and Weir 32 in January 2022. *Source: DPE-Water*.

after the fish deaths. However, there were gaps in the continuous monitoring of DO including the ~40 km river stretch between the upper lakes outlets and Weir 32, where significant deaths were recorded.[125] There is an approved program of works for DO sensors across the basin that is yet to commence at the time of writing.[126] Installation of DO sensors needs to be prioritised at sites upstream, both within the lakes and in the Lower Darling-Baaka River before the summer of 2023-24. This is critical for early detection of the risk of further fish deaths of hypoxic conditions associated with higher temperatures. Consideration needs to be given to monitoring both shallow and deeper layers at sites, rather than a single depth.

- **Algal monitoring –** the detection of an algal bloom in August indicates the need for a year-long monitoring program, prior to temperatures increasing (e.g. summer) and flows declining (e.g. during drought conditions).
- **Sediment sampling –** routine sediment sampling should be incorporated into the ongoing monitoring program to detect longer term trends and support strategies for mitigating risks of future fish deaths.

Recommendation 2.1

A NSW (state-wide) water quality and monitoring strategy, implemented within 12 months, which is publicly available and updated regularly, including quarterly progress reports on its development. The strategy should encompass or be linked to:

- an early warning system drawing on improved monitoring and modelling and a plan to activate strategies to mitigate fish death events
- an evaluation and adaptive learning program informed by improved real-time data, modelling and assessment of the effectiveness of interventions to improve water quality and system health and resilience.

Recommendation 2.2

Accelerate the work program for installing dissolved oxygen sensors in high-risk areas, particularly the Lower Darling-Baaka where several major fish death events have occurred in recent years.

3.5.2 An open data regime

A water data regime is required that adopts a whole-of-system and integrated approach to data collection, analysis and management in order to strengthen predictive capabilities, adaptive learning and decision-making**.** This regime should include a default position of open data **–** being data for decision-makers that is high-quality, readily accessible, in usable formats and transparent in its assumptions and applications.[127]

Improvements in the transparency and accessibility of data are needed. For example, the Review found that some information and trend data integral to understanding factors contributing to the fish death events was not readily available, required special requests or was available in formats that did not enable the data or assumptions to be interrogated or readily analysed. Similarly, data reporting via websites and in PDF form is still allowed, including for example, environment protection licences issued by the NSW Environment Protection Authority. Reporting publicly funded data directly and on a real-time basis into

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[125] This led to incident-based sampling by field staff to help inform response efforts.

[126] Prior to the 2023 fish deaths, funds were approved for installation of DO sensors at 40 additional sites in the Basin as agreed by NSW and Commonwealth Government agencies. Installations were to commence in 2022-23 but this work program was hampered by flooding and it was deferred to 2023-24. *Source: DPE-Water*. The Review understands additional fixed depth sensors are proposed for the Darling-Baaka River at Tilpa, Lake Wetherell, Menindee railway bridge, the Darling River at Menindee and at Pooncarie, and profile monitoring for Lake Wetherell, Main Weir, Weir 32 (where there is current fixed depth monitoring) and Pooncarie.

[127] This is defined in the Chief Scientist & Engineer's Review of water-related data collections, data infrastructure and capabilities report. Progress in giving effect to the recommendations contained in the water data report is acknowledged. However, this Review found key data are still not readily and publicly accessible in a useable format. *Source: Chief Scientist & Engineer (2020). Review of Water-related Data Collections, Data Infrastructure and Capabilities.*

federated datal portals (such as SEED) should be the default position and a requirement for individuals and agencies.

Assumptions underpinning decisions must also be more transparent. For example, the method used to estimate evaporation from the Lakes was repeatedly questioned by community members. Currently data on losses (including evaporation) is aggregated and there is little information in the public domain about the methodology and inputs to calculations.[128] At the same time, evaporation is an underlying driver for operating decisions relating to preferred water storages and the order in which water is released from the Lakes, which in turn has implications for the quality of water in the weir pool. Transparency about the volumetric and quality implications of using different outlets is also needed.

The Review sought advice on the development and use of probabilistic models and the feasibility of developing a catchment digital twin to provide early warning of impending critical events, and to mitigate risks. While attractive, it was suggested that a Basin-wide digital twin was challenging at this point, given the complexity of the system. However, a simplified approach was proposed as feasible, focusing on (a) critical parts of the system and (b) using only a small number of factors to signal risk. For example, risk scenarios could be tested utilising DO as a system state signal and flow velocity data as a critical management lever. Over time, combining simplified models with machine learning algorithms and real-time data could provide more sophisticated insights. Given the high-risk of recurrence, this approach is recommended as a priority.

Recommendation 2: Better decisions require better data

An integrated, open, whole-of-system approach to data collection, analysis and management needs to be established. This is essential to enable timely and transparent decision making and build trust in the community. This water data regime should be based on the following principles:

- the data must cover the whole of the river system as all parts are connected. The monitoring network needs to be expanded to address key gaps (e.g. sites, resolution, and indicators)
- the data must minimally cover water flow rates and water quality (including dissolved oxygen), fish and algal biomass, and monitoring cause and effect variables to provide early warning of deteriorating conditions and ecosystem response
- the data must be open and accessible to all (Findable, Accessible, Interoperable, and Reusable – FAIR).
- investment in new sensors and technology platforms (including telemetry), and their maintenance, to provide adequate coverage and warning
- development and use of probabilistic models and baseline steps towards a catchment digital twin, drawing on real time data, machine learning algorithms and insights
- recognition and integration of community observations and Aboriginal Knowledge as important sources of evidence.

[128] Sinclair Knight Merz (2010) Darling River Water Saving Project Part B – Final Report.

4. Governance, policy and operations

A recurring theme in submissions and consultations was the long-term decline in water quality and the ecosystem of the Darling-Baaka River. The 2023 fish deaths, and indeed earlier fish deaths, are a 'canary in a coal mine' event, reflecting broader ecosystem degradation and declining resilience to the challenges posed by human interventions, infrastructure and climate change. Contributing factors cited include the complex governance system and weaknesses, and gaps in legislative, policy and water sharing plan provisions (for convenience, the 'regulatory framework'), rules and operational protocols.

This chapter recommends actions to address these issues, aiming to improve both water quality and flows to the Lower Darling-Baaka River and consequently ecosystem health and resilience. Delivering these recommendations and the intended outcomes is not a trivial task. Challenges include the spatial scale of the basin itself, inter-jurisdictional interests and oversight, and numerous interdependencies (natural and human) affecting ecosystem health and performance.

Figure 25 sets out Basin management roles and responsibilities in functional groupings as they affect the Menindee Lakes system. This approach highlights:

- the numerous agencies at Commonwealth, state and local level, even within a single functional area
- the need for mission clarity and coordination within *and* between functional groupings to effect outcomes
- that while the Lakes system is in NSW, that state does not directly control all relevant activities affecting the ecosystem within its borders.

For this reason, a single (lead) agency in NSW should be tasked with the responsibility and oversight for implementing and reporting progress against recommendations contained in this report. An individual with local knowledge and community connections, located in Menindee, should be appointed under the umbrella of this agency. This lead agency should immediately develop a delivery plan for implementing recommendations and publicly reporting progress. The plan must include defined responsibilities and targets against which progress and impact can be clearly measured in defined timeframes (i.e. 3, 6, 12 months, 5 years). The plan must encompass working and advisory groups as well as agency responsibilities and actions involving interface with the Commonwealth and other jurisdictions.[129] Ideally, the lead agency would have broader authority to oversee water-related decisions including the interface between land and water planning and decision-making in NSW. This role should be separate to systems operations and other roles that may give rise to potential, perceived or actual conflicts in decision-making.

Recommendation
A lead agency should be clearly tasked with responsibility and oversight for implementation and reporting progress against the recommendations contained in this report.

Other regulatory and policy actions needed to improve ecosystem health and functionality include the following, which are dealt with in turn in the remainder of this chapter:

- ensuring environmental protections are enforceable
- taking steps to improve Basin connectivity
- reviewing and strengthening plans and operational protocols to improve environmental outcomes.

[129] Stakeholders and Expert Panel members commented on the changing composition of working groups over time and the lack of clarity of roles, operations and functions. For example, the Hypoxic Blackwater Working Group appears highly regarded as a mechanism for engaging and coordinating relevant agencies to manage events. However, at the time of the Review, its role was not formalised, minutes were not public and its triggers for action unclear.

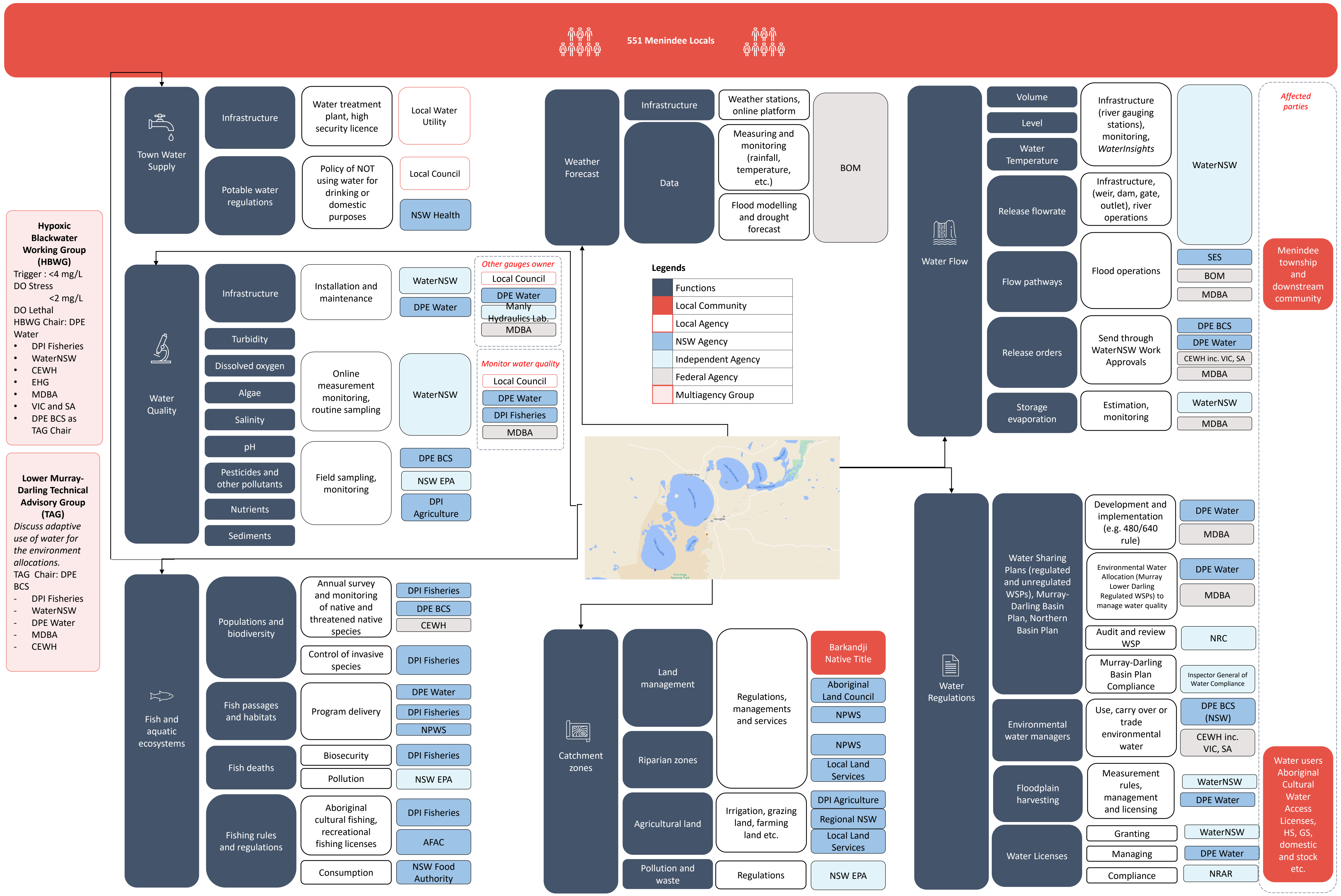

Figure 25: Agency basin management functions, roles and responsibilities. *Source: OCSE.*

4.1 Environmental protections must be enforceable

The Objects and Principles of State and Commonwealth legislation, including Water Sharing Plans, contain clear provisions for environmental health, protection and restoration, including at basin and state scales.[130] However, current operations and rules permit activities that work against these objectives, and there appear to be no consequences for failing to deliver against these objectives.

A catchment-scale regulatory framework is needed that directly connects land and water decisions and provides a mandate to set permissions, enforce actions and substantively address non-compliance. Data and expert advice provided to this Review make clear that without substantive change there will be further environmental degradation and recurrence of ecologically catastrophic events. Existing provisions are available to support this approach.[131]

A fit-for-purpose regulatory framework to give effect to statutory objects requires:

Steps to establish obligations and powers

This includes assigning duties, authority, consequences and metrics.[132] There should be incentives to encourage compliance by individuals and agencies, and substantive consequences for a failure to execute.

Imposing duties in law through statutory authorisations (e.g. permits or licences) is well established in Australian and international planning and environmental law systems, including for environmental protections.[133] Imposing duties through authorisations is proposed as a pragmatic means of addressing current caselaw limits on the meaning and use of statutory objects.[134] The framework has three components:

- defining the scope of what 'the river' encompasses. Ecological concepts and mapping of the river and surrounds should be adopted, at catchment scale, to promote inter-valley connectivity[135]
- establishing measurable duties and obligations for the use or take of water that are SMART (specific, measurable, achievable and relevant to the stated regulatory goals or objects),[136] and include whole-of-catchment impacts (upstream and downstream effects)

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[130] See for example The Cth *Water Act 2007* No 137, the NSW *Water Management Act 2000 No 92*, the NSW *Protection of the Environment Operations Act 1997 No 156*, the NSW *Fisheries Management Act 1994 No 38*, the NSW *Environmental Planning and Assessment Act 1978 No 203*, the NSW *Biodiversity Conservation Act 2016 No 63*. An overview of Water Sharing Plans is in Appendix 10.

[131] For example, there is provision for a State Water Management Outcomes Plan (Division 2, S.6) in the *Water Management Act 2000*.

[132] An alternate approach is recognition of the rights in law of natural entities as legal persons or living entities, for example, the Ganges and Yumuna Rivers in India (*Salim v State of Uttarakhand* (2017) Writ Petition (PIL) No.126 of 2014 [High Court of Uttarakhand] 2017 and the Whanganui River in New Zealand (*Te Awa Tupua (Whanganui River Claims Settlement*) Act), 2017 (New Zealand). In Australia, the Yarra River (Victoria) has been recognised as a living entity although it does not have legal personhood under the *Yarra River Protection (Wilip-gin Birrarung Murron) Act 2017* (Vic). However, there are limitations with assigning human rights to non-human entities e.g. The Ganges and Yahuna Rivers decision is under appeal, in part because the risk of legal action against guardians appointed to protect the rivers interests (such as damage or death associated with flooding).

[133] For example, section 20 of the Finnish Constitution provides that 'Nature and its biodiversity, the environment and the natural heritage are the responsibility of everyone'. Non-environment examples include development certifications and building permits; environmental examples including Ramsar Convention designation, Planning Secretary environmental assessment requirements (SEARs) and Environment Protection Licences.

[134] See, for example, J.K. Williams Staff Pty Limited v Sydney Water Corporation [2021] NSWLEC 23 at [163]-[169].

[135] Including, for example, the river proper (water), biota, macrobiota and water-dependent species, floodplains and the historic river footprint. A catchment-scale approach is designed to address the weakness of valley-specific targets in current Water Sharing Plans.

[136] Performance measures should include iconic and long-lived species such as river mussel (*Alathyria jacksoni*), Murray cod and River Red Gums (*Eucalyptus camaldulensis*), culturally significant species, native species indicative of river health or with a role in ecosystem maintenance and functional measures of ecosystem health such as nutrient cycling, carbon flux and sedimentation rates. Ecological community measures should include functional and taxonomic diversity, and plant cover.

- implementing a strengthened approvals system that requires:
  - conditions to be consistent with statutory environmental objects, with the regulator obliged to refuse an approval if it is not satisfied that the take of water is consistent with those objects
  - a requirement for approving authorities and regulators to assess and account for cumulative impacts of any approvals. Transparent guidance on the exercise of functions is required, including criteria to be applied.

Local knowledge and data

These are essential for success and require ongoing resourcing. Local knowledge includes engaging with and drawing on Aboriginal peoples' knowledge of catchment riverine systems and species management[137] and other local community knowledge of the river and 'what works' in relation to: design of prevention and response strategies, performance indicators and triggers and operational plans, and establishment of mechanisms for advancing understanding and opportunities for community to regularly interrogate implementation progress, monitoring, data analysis and reporting.[138]

Data collection

An integrated, open and whole-of-system approach should be established to facilitate data collection, analysis and management to enable timely and transparent decision-making as outlined in Chapter 3.[139]

Recommendation 1: Regulatory environmental protections must be enforced

The regulatory framework must be upgraded to include legally enforceable obligations and powers to give effect to environmental protections and whole of catchment ecosystem health, as expressed in the objects of water, environmental and biodiversity legislation.

Changes should:

- draw on scientific, cultural and local community insights and be developed in partnership with these knowledge communities
- address risks to the Lower Darling-Baaka and its water-dependent ecosystems
- be informed by an independent review of existing water rights, water accounting systems, exercise of rules and operational parameters, and their impact on riverine catchment health. This includes provisions in Water Sharing Plans to improve water flow across the system
- be based on much improved real-time data and monitoring of the whole river system.

4.2 Improving system scale connectivity

Submissions to the Review and stakeholders expressed concern about the management of the northern Basin, including water use and pollution from upstream. The Review examined data indicating an association between decreased flows in the Barwon-Darling and Lower Darling-Baaka River and increased water take from the northern Basin. This is discussed in Chapter 2.

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137 Akin to the embedding of cultural burning practices in fire management strategies.

138 To illustrate, a simple measure of success is to contrast reports from the local community in 12 months' time with the 2018 witness statement of Mr William Brian Bates to the Murray-Darling Basin Royal Commission. *The Murray-Darling Basin Royal Commission Report and Witness statement.*

139 A default position of open data as defined in the Chief Scientist & Engineer's review of water-related data collections, data infrastructure and capabilities. Progress in giving effect to the recommendations contained in that report is acknowledged. However, this Review found key data is still not readily and publicly accessible in a useable format. *Source: Chief Scientist & Engineer (2020). Review of Water-related Data Collections, Data Infrastructure and Capabilities.*

The Review is aware of steps being taken to improve hydrological connectivity via the protection of flows and other initiatives, with '*improving connectivity across the northern Basin*', a priority of the Western Regional Water Strategy.[140] This strategy aims to improve connectivity across the northern Basin and the health and resilience of natural systems.[141]

For example:

- protecting flows through temporary water restrictions[142]
- introduction of the *active management mechanism* in some northern Basin valleys to protect water for the environment[143]
- changes made to the Barwon-Darling WSP to protect the critical first flows after an extended low-flow or dry period[144]
- review of the North West Flow Plan including algal suppression, fish movement and riparian flow targets to better support environmental and community needs, including storage for the upper lakes i.e. Lakes Wetherell and Pamamaroo[145,146]
- amendments in 2022, to the Border Rivers and Gwydir WSPs to restrict floodplain harvesting when the combined volume in Menindee Lakes is below 195GL to provide for downstream critical needs.[147]

While these are important steps, there is a need to adopt a holistic approach and consider all components of the flow regime and how they contribute to meeting environmental water requirements. Notably, recent reforms have largely focused on low flows and do not consider the spectrum of the flow regime. Consideration also needs to be given to protecting flows in and from northern Basin unregulated rivers. For example, the flow targets from the North West Flow Plan currently only apply to regulated river water sources (supplementary access) and the Barwon-Darling (B and C class).

Protecting flows in the northern Basin has the potential to contribute to outcomes in the Lower Darling-Baaka and southern Basin, including water dependent ecosystems. However, this is not explicitly recognised in current policy. If flows in the northern Basin are afforded better protection, they could contribute to inflows to Menindee Lakes and help mitigate some of the challenges associated with managing the upper lakes as a drought reserve. Flow targets for the Lower Darling-Baaka should be a focus of improving system connectivity.

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140 NSW Department of Planning and Environment (2022) Regional Water Strategy: Western.

141 Actions outlined in the strategy are intended to protect the first flush of water after an extended drought, protect human and environmental needs, reduce the impact of cease-to-flow periods and improve low-flow connectivity, suppress algal blooms and support fish migration (including through the review of the North West Flow Plan).

142 In 2018, following extended cease-to-flow conditions in the Barwon-Darling, temporary water restrictions were used to protect water for the environment, leading to connection of pools over 2,000 river kilometres in the northern Basin to just downstream of Wilcannia. These restrictions were needed as WSPs did not (then) include provisions to protect flows which comprised held environmental water*. Source: Department of Agriculture, Water and the Environment (2019) .Final Report on the Northern Connectivity Event (April – July 2018)*.

143 Mainly held environmental water, with the exception of the Macquarie-Bogan where planned environmental water (environmental water allowance sub-account 2) is afforded protection.

144 This amendment addressed concerns expressed in the 2019 CEWH submission to the NRC for the review of the Barwon-Darling WSP; DPE-Water Cease-to-flow periods in the Barwon-Darling and others about meeting critical human and environmental needs following a resumption flow event.

145 The Interim Unregulated Flow Management Plan for the North West was designed to provide water for algal suppression, fish movement and riparian needs. Developed in 1992, the plan had not been consistently implemented but a recent review recommended changes to the plan's riparian flow targets, algal suppression target and fish flow targets. Rules were placed on supplementary access by some licence holders in regulated rivers in the northern Basin. The original NNF Plan included riparian and algal suppression targets as far as Wilcannia and fish migration targets for Brewarrina and Bourke. It did not extend to Menindee Lakes or the Lower Darling-Baaka. *Source: Department of Water Resources (1992). Interim Unregulated Flow Management Plan for the North-West.*

146 Alluvium (2022). Review of the Interim Unregulated Flow Management Plan for the North West.

147 However, stakeholders have questioned the adequacy of this trigger. *Source:* Clause 43B(3) of the Water Sharing Plan for the NSW Border Rivers Regulated River Water Source 2021 requires that the Minister must not announce that the taking of overland flow water is permitted if the volume of water stored in Menindee Lakes Storage is less than 195 gigalitres.

The NSW Government has recently established the Connectivity Expert Panel to provide independent advice to the Minister for Water on the adequacy of proposed changes to flow targets in the Barwon-Darling and northern Basin regulated river WSPs (based on review of flow targets in the North West Flow Plan) and to advise on in-valley and Menindee Lakes triggers for restricting floodplain harvesting and opportunistic take to protect the first flush following an extended dry period.

Recommendation 1.1
Ensure the newly convened Connectivity Expert Panel examines the adequacy of rules in all northern Basin water sharing plans (regulated and unregulated) in contributing to hydrological connectivity with the Lower Darling-Baaka River and southern Basin.

Recommendation 1.2
Prioritise changes to water sharing plans in the northern Basin based on findings of the Connectivity Expert Panel, with the intent of improving outcomes through the system including in the Lower Darling-Baaka River.

4.3 Plans and operational protocols

Figure 26 sets out the inter-relationship between key Commonwealth and NSW water legislation, plans and approvals associated with the management and operation of Menindee Lakes and the Lower Darling-Baaka River. The laws, plans and approvals include provisions for which agency has authority to make decisions under different circumstances and rules around operations and allocations.

As noted in the *Independent Assessment of the 2018-19 fish deaths in the lower Darling*, water management in NSW has historically largely been segmented by water management areas.[148] This is evident in several NSW WSPs and the way water resources have been managed in the northern Basin.

The WSP that applies to the Lakes and the Lower Darling-Baaka River (the MLD Plan) is due to expire on 30 June 2026.[149] Prior to this date, the extent that the plan has contributed to environmental, social, cultural and economic outcomes is due for review by the Natural Resources Commission (the NRC Review).[150]

The following sections discuss issues with the MLD Plan, including inadequacies in plan provisions for managing the events like those experienced in March 2023 and the importance of revising risk assessments based on the latest information.

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[148] Vertessy, R., Barma, D., Baumgartner, L. et al. (2019). Independent Assessment of the 2018-19 Fish Deaths in the Lower Darling: Final Report.

[149] Details of the WSPs are in Appendix 10.

[150] In accordance with Clause 43A, Division 8, Part 3 of the *Water Management Act 2000*.

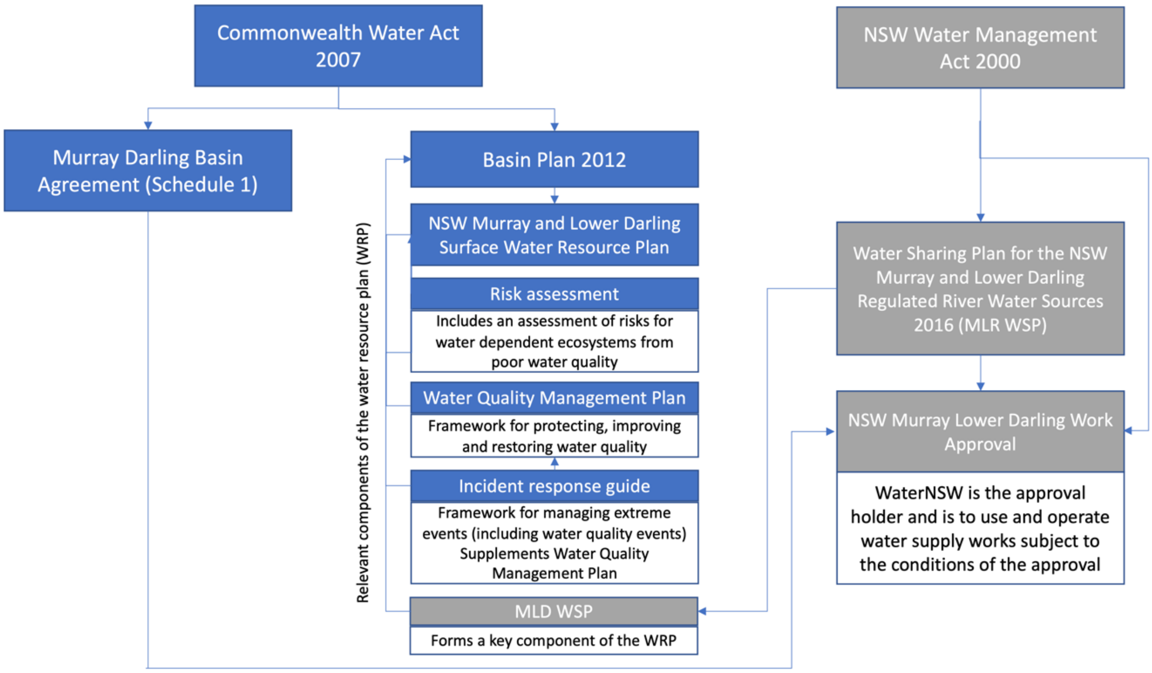

Figure 26: Legislation, planning instruments and approvals that apply to Menindee Lakes and the Lower Darling-Baaka River.
Source: OCSE.

4.3.1 Changes to water sharing plans are needed

The MLD Plan includes a 30GL Lower Darling Environmental Water Allowance (EWA)[151] which can be used for reducing salinity, managing dissolved oxygen levels and mitigating impacts associated with blue-green algae.[152] The EWA was used to manage water quality (to maintain dissolved oxygen between the Main Weir and Lake Menindee Outlet above critical thresholds) in the lead up to the March 2023 fish death event.[153] Release of the EWA in addition to flood recession releases provided some temporary improvement in dissolved oxygen levels. However conditions declined when the EWA was exhausted. Key issues with the Lower Darling EWA that should be addressed in the NRC Review include:

- **insufficient volume** – the 30GL allowance was not adequate to mitigate the water quality issues and subsequent fish deaths in March 2023. This water was exhausted in three weeks (by 16 March 2023), with the EWA accounting for just 15% of environmental water released into the Lower Darling-Baaka to 30 June 2023.
- **not available in drier years** – the EWA is only available during years that the combined Lakes storage exceeds 640GL. It is not available for use in drier periods when the combined storage volume is below 480GL and under NSW control, limiting the times when this allowance is available for managing water quality issues that may cause fish deaths.
- **lacks rules for when it is more beneficial to release the EWA from the upper lakes** – the MLD Plan does not specify conditions or triggers for when the EWA is released from the upper lakes to mitigate water quality issues between the Main Weir and Weir 32. WaterNSW currently has discretion over which lake(s) releases are made from to manage drought reserves. This could reduce the effectiveness of the EWA provision in certain situations. For example, water releases from Lake Menindee Outlet would not be as effective in addressing water quality issues in the upper weir pool (below Main Weir), as releases made from Lakes Pamamaroo or Wetherell.

[151] For the purposes of this report, EWA refers to the Lower Darling Environmental Water Allowance unless otherwise indicated.
[152] Clause 64(3), Division 2, Part 10 of the Water Sharing Plan for the Murray and Lower Darling Regulated River Water Sources 2016.
[153] Clause 64 of Water Sharing Plan for the Murray and Lower Darling Regulated River Water Sources 2016.

Recommendation 1.3
Prioritise the review of the Water Sharing Plan for the Murray and Lower Darling Regulated River Water Sources 2016 with a focus on the adequacy of Plan provisions for meeting environmental and water quality objectives.

4.3.2 The Lower Darling Environmental Water Allowance is insufficient

The inadequacy of the EWA as a response to low dissolved oxygen in the lead up to the March 2023 fish deaths was acknowledged by DPE-Water during this Review.[154] It led to the reliance on held environmental water to manage the event. The current EWA provision is unlikely to be sufficient to mitigate future events of this scale, particularly if there is a significant fish biomass in the reach between Main Weir and Weir 32 and a lack of suitable fish passage into the upper lakes. Stakeholder submissions also expressed concern about the risk of exhausting the EWA account before the spring and summer of 2023-24, leaving no other alternative to manage the water quality of the Lower Darling-Baaka River.[155]

As at 9 August 2023, around 2GL of the 30GL of the EWA available for the 2023-24 water year had been released into the Lower Darling-Baaka River in response to algal blooms. As has been previously explored, these blooms are atypical and are likely attributed to the decomposition of fish that perished in March 2023 as well as warmer winter temperatures. It is highly plausible there will be a further need for the EWA moving into spring-summer 2023-24, particularly given the Menindee region's climate forecast for last quarter of 2023.

Further analysis of environmental water provisions and their adequacy for contributing to environmental outcomes should be a focus of the NRC review of the MLD Plan. DPE-Water has analysed the value of amendments to the EWA when Menindee Lakes are under NSW control (combined storage below 480GL) to manage water quality issues during periods of low flow.[156] The modelling found that an average annual volume of 26.6GL was needed, while 58.4GL was required in at least 25% of years.[157]

Since this work was undertaken, the MLD Plan was amended to include a Lower Darling-Baaka River flow restart allowance, which is available when the combined volume of Menindee Lakes is below 480GL.[158] Up to 60GL is available under this allowance, which can be used for recommencing flows when the Darling-Baaka River at Weir 32 has ceased to flow for ten consecutive days. Had this volume been available at the time of the fish deaths, there may have been less reliance on held environmental water. This provision could be explored for periods when the Lakes are above 640GL for managing water quality events (to provide for a larger volume of planned environmental water than the current 30GL EWA). However, its effectiveness is also contingent on where the releases are made from. Additional rules may be necessary to override operator discretion and ensure environmental outcomes are prioritised consistent with legislation (as above).

4.3.3 Reliance on held environmental water for water quality issues is not sustainable

Environmental water holdings comprised the greatest volume (85%) of water used to manage the water quality issues and mitigate further fish deaths in the Lower Darling-Baaka in the first two quarters of 2023 (Figure 27). The volume was significant. More held environmental water was released into the Lower Darling-Baaka River between mid-March to late June 2023 than in the several years prior.[159] Use of held

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[154] NSW Department of Planning and Environment, Water Group (2023). Fish Deaths in the Darling-Baaka River – Part A (*Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee*).

[155] Commonwealth Environmental Water Holder (2023) Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee.

[156] Undertaken as part of the development of the Western Regional Water Strategy.

[157] NSW Department of Planning and Environment (2022) Regional Water Strategy: Western.

[158] Clause 72 of Water Sharing Plan for the New South Wales Murray and Lower Darling Regulated Rivers Water Sources Amendment Order 2022.

[159] Commonwealth Environmental Water Holder (2023) Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee.

environmental water as part of the response to the event was beyond the watering actions that were outlined in the NSW Murray and Lower Darling-Baaka Annual Environmental Water Plan.

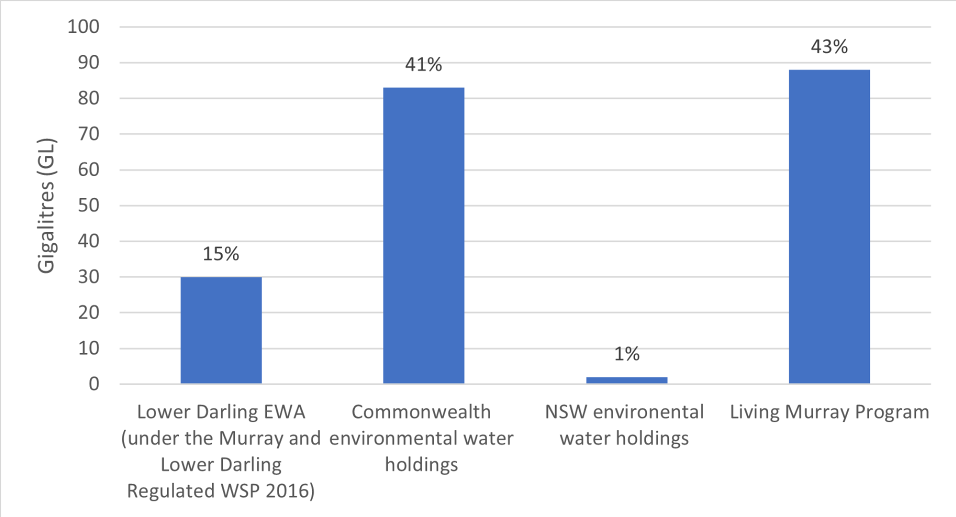

Figure 27: Use of environmental water in the Lower Darling-Baaka River. Total volume used under each allocation, and percentage of the total 203GL used to manage water quality and mitigate fish deaths in the Lower Darling-Baaka River in the 2022-23 water year**.** *Source data: Commonwealth Department of Climate Change, Energy, the Environment and Water*.[160]

Policy gaps were identified with respect to the reliance on environmental water holdings in managing the March 2023 fish death event. Environmental water holders incurred the cost of the event.[161] During the Review, significant opportunity costs associated with use of held environmental water were revealed, as well as the financial cost of approximately $700,000 in usage charges.[162]

The use of environmental water holdings in response to fish deaths impacts on the availability of this water for other planned environmental watering events. This concern was raised by a range of stakeholders. The CEWH's submission to the Review states that:

> … *the operation of the NSW Murray and Lower Darling Surface Water Resource Plan and WSP to manage resource risks to both the environment and communities should contain effective risk management strategies and procedures that do not rely upon held environmental water to underpin the operation of the WSP*.[163]

Given the Lakes are operated as a shared resource, the management of water quality issues is arguably also a shared responsibility, particularly when the combined lake levels are above 640GL. Sharing responsibility for managing water quality issues in the Lower Darling-Baaka should be explicitly enshrined in the Murray Darling Basin Agreement (the Agreement). This is consistent with the improvement and maintenance of water quality in the Murray River, which already forms part of the Agreement.[164] This would mean that provisions for managing water quality in the Lower Darling-Baaka would not sit solely in the NSW MLD Plan.

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[160] Water for the environment (planned and held environmental water) as a percentage of the total volume of 203GL that is used to manage water quality and mitigate fish deaths in the Lower Darling-Baaka River in the 2022-23 water year.

[161] NSW Department of Planning and Environment, Water Group (2023). Fish Deaths in the Darling-Baaka River – Part A (*Submission to the Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee*).

[162] NSW Department of Planning and Environment, Environment and Heritage Group pers comm 29 Aug 2023.

[163] The modelled scenario was a flow threshold of 1,000ML/day at Burtundy based on a simulation of conditions where algal blooms may be present.

[164] Clause 98(4)(i) of the Murray Darling Basin Agreement, Schedule 1, Commonwealth *Water Act 2007*.

Stakeholders consulted as part of the Review proposed that responses to water quality events and fish deaths where river regulation is a contributing factor, should be a shared responsibility. Revisions to operating arrangements should consider the needs of the environment of the Lower Darling-Baaka River and how the Lakes can be operated as a shared resource to maintain and improve river health, including water quality. However it is clear that minimum adequate levels of water should be available irrespective of who is in control of decision-making. It is acknowledged that changes to the Agreement for this purpose may have an impact on water users.

Recommendation 1.4
Explore the extension of existing provisions for water releases when the lakes are under the direction of the MDBA that are currently only available when the combined volume of Menindee lakes is below 480GL.

Recommendation 1.5
In consultation with the MDBA, explore how the management of Menindee Lakes as a shared inter-jurisdictional resource can be better managed to mitigate water quality and fish deaths in Weir 32 weir pool (or Menindee weir pool).

4.3.4 Operator discretion risks outcomes for the Lower Darling-Baaka

At present, water orders from Menindee Lakes are made to WaterNSW and are measured at Weir 32. Environmental water managers may nominate their preferences in terms of which works environmental releases are delivered from. However, WaterNSW has discretion over where the releases are made to meet the water order. The Review was advised there is a preference to make releases from Lake Menindee which has presumed higher evaporative losses than the other lakes. However, releases made from the Lake Menindee Outlet effectively bypass a large stretch of the river near Menindee and are not as effective as releases made from Lakes Pamamaroo and Wetherell for managing water quality issues and fish deaths further upstream in the weir pool between Weir 32 and Main Weir.

For this reason, it is important to review current river operator discretion and embed operating rules in the MLD Plan and WaterNSW's works approval to cover releases from the upper lakes intended to manage significant water quality issues and fish death events in this body of water. Codifying these arrangements in the MLD Plan would also contribute to achieving water sharing plan objectives. However, the requirements of the Murray-Darling Basin Agreement must also be considered.

Recommendation 1.6
Develop triggers for when water is to be delivered from the upper lakes into Weir 32 weir pool (or Menindee weir pool) for mitigating water quality issues and the risk of mass fish deaths recurrence.

4.3.5 Water quality risks and management strategies require review

The MLD WSP forms a component of the NSW Murray and Lower Darling Surface Water Resource Plan (Figure 21).[165] The water resource plan includes a Water Quality Management (WQM) Plan which provides a framework for protecting, improving and restoring water quality including reducing salinity.[166]

A key issue with the WQM is that the underpinning analysis is based on data from 2010-15, and therefore does not incorporate recent events including mass fish deaths associated with low dissolved oxygen (DO). For example, the Plan indicates that annual median DO results were lowest in the Lower Darling at

[165] The MLD WSP is a component of the NSW Murray and Lower Darling Surface Water Resource Plan developed by the NSW Government in accordance with Basin Plan requirements This water resource plan has not yet been accredited and was resubmitted to the MBDA for assessment in August 2023.

[166] The Water Quality Management Plan is a requirement under Chapter 10, Part 7 of the Basin Plan. *Source:* *NSW Department of Planning, Industry and Environment (2019). Basin Plan 2012: NSW Murray and Lower Darling Surface Water Resource Plan – Water Quality Management Plan – Schedule H.*

Menindee Weir 32 and at Burtundy, but within the target range at most other sites in the Plan area. Currently, a DO reading that is outside the target range for water-dependent ecosystems is categorised as only a medium risk to the Darling River at Weir 32 and Burtundy.

There are a number of actions included in the WQM plan for maintaining DO within target ranges.[167] However, these need review as to their adequacy in light of 2023 fish death events. For example, the release of EWA is limited in specific circumstances.[168] Both the WQM Plan and underpinning risk assessment need to be revised. In particular, the risk profile between Main Weir and Weir 32 requires attention. This work needs to align with the state-wide water quality plan recommended by this Review.

Recommendation 1.7

Review the risk assessment and mitigation strategies for managing low dissolved oxygen included in the Murray and Lower Darling Water Quality Management Plan to reflect water quality issues and mass fish deaths observed in 2018-19 and 2022-23.

[167] Strategies include implementing minimum flows from the Menindee Lakes to the Lower Darling River as outlined in WaterNSW works approval as prescribed by the Murray-Darling Basin Agreement (Schedule 1 of the Commonwealth Water Act 2007); releasing the EWA strategic use of held environmental water.

[168] As provided under Clause 64 of the Water Sharing Plan for the Murray and Lower Darling Regulated River Water Sources 2016. As noted previously however, the EWA is only available in certain circumstances (when the lakes are above 640GL) and was not sufficient for managing low DO in the lead up to the March 2023 fish deaths. Further, managing water quality events that the WSP is intended to do is not the purpose of held environmental water.

5. Emergency management

This chapter discusses the Emergency Management (EM) response to the March 2023 event and what can be done to improve future responses. This includes communication with and involvement of rural and remote communities and the use of established EM processes. Insights from earlier events, including February 2023 also informed this Review.[169]

Key findings

- Lack of connection/communication between the water management agencies and the EM response.[170] Limited preparation and planning was undertaken with no apparent communication between the two functions. Deteriorating water quality, fish deaths prior to March 2023 and other environmental signals, should have served as early triggers for the need for an EM response.
- The EM response was delayed as there was no defined agency accountability for leading the event response. There was confusion about agency responsibilities and a reluctance to commit resources due to a lack of understanding about funding arrangements. Consequently, only a small fraction of the fish was collected and disposed of.
- Not all Local Emergency Management Committee (LEMC) participants and NSW Government agencies understand the EM framework.
- The establishment of the Emergency Operations Centre (EOC) by NSW Police, led by the Local Emergency Operation Controller (LEOCON) and Regional Emergency Operation Controller (REOCON), saw a coordination of resources to the emergency public health response, particularly once key knowledge holders were involved (such as NSW Health, Aboriginal Affairs and the National Parks and Wildlife Service).
- There was a lack of coordination when messaging the community, including a lack of two-way communication. This is despite a stated willingness of the community conveyed to the Review team during community listening sessions to contribute both their on-ground observations and local experience.

5.1 State Emergency Management Framework

The NSW EM arrangements are set out by the NSW State Emergency Management Plan (the EMPLAN),[171] as legislated under the *State Emergency and Rescue Management Act 1989* (SERM Act).[172] Together, the EMPLAN and SERM Act establish the principle of a lead agency (e.g. a 'combat agency' that has responsibility for leading the emergency response, such as NSW Rural Fire Service for bushfires) and the Functional Areas (the Functional Areas that are involved in the planning for, preparation for, responses to or recovery from an emergency). Details about the EMPLAN and SERM Act and a description of the key terminology and acronyms within this chapter can be found in Appendix 11. For the purposes of reviewing the fish death events, the value of both the EMPLAN and the SERM Act are the principles and structure they provide to shape roles and responsibilities before, during and after the activation of an EM response.

5.2 March 2023 emergency triggers and response

The initial trigger for the EM response emerged on 17 March 2023 was social media and news reports of very large numbers of deceased fish in the Menindee vicinity. Figure 32 contains a timeline of events. The Review team attended the EOC post-action review, consulted with government agencies and the community about the timeline and their understanding of the March 2023 event, the consequential emergency process, and its associated communications.

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[169] Although there was a localised emergency response to the preceding February 2023 event, there was no requirement to escalate to an all-agency, formalised emergency management response due to the scale and manageability of events. However, it highlighted the need to review the appropriateness of current triggers, thresholds and associated actions.

[170] For example, both the Hypoxic Black Water Group (HBWG) and WaterNSW Incident Management Team (IMT) were stood up to monitor water quality since October 2022.

[171] NSW Government (n.d.). State Emergency Management Plan (EMPLAN).

[172] State Emergency and Rescue Management Act 1989 (No. 165).

Date	Events	Agencies
Leading up to… FEB 2023	• Conditions led NSW agencies to believe that there was a known risk of fish deaths since October 2022: this includes at least 30 reported fish kill events across NSW (at least nine in the vicinity of Menindee) prior to the February and March fish kill event • Hypoxic Black Water Group (HBWG) established (October 2022) in response to widespread flooding in the Central and Far West regions. WaterNSW Incident Management Team (IMT) also established	- HBWG - WaterNSW IMT
FEB 24	• DPE Water Community Update: February fish kill event	- DPE Water
MAR 10	• DPE Water Community Update: ongoing update from February event	- DPE Water
MAR 16	• HBWG routine testing showed the dissolved oxygen (DO) within the river upstream of Menindee had dropped below 2 mg/litre and informed water operation organisations • First report of fish deaths near Menindee township appeared on social media and local news	- HBWG
MAR 17	• Reports also coming to Council; SEOCON and DPI made aware of hypoxic water event • SEOCON informed by DPI that the Minister for Lands and Water had instructed WaterNSW to lead the response to the emerging fish kill situation; however, this was not formally communicated through • DPE Water Community Update: fish death notification for Menindee	- Central Darling Shire Council - NSWPF (SEOCON) - DPI - Central Darling Shire Council - NSWPF (SEOCON) - DPE Water
MAR 18	• Ongoing media reports and social media indicating increased extent of fish deaths • Discussion occurs between the Council and Reconstruction Authority, regarding concern for the impact of the emerging fish kill event on water quality • Reconstruction Authority subsequently contacts SEOCON • SEOCON contacted REOCON, who subsequently contacted LEOCON, requesting extraordinary LEMC to be held and EOC to be opened 15:30 • Extraordinary LEMC held; Central Darling R/LEOC opened • Consensus from DPI, DPE Water and WaterNSW is that the fish death was a result of a hypoxic blackwater event (low DO); estimated mass fish death of ~20-30 million • Four working parties established to address EOC issues 16:00 • DPE Water meeting was to be held at this time; subsequently cancelled due to the LEMC meeting overriding the need for this meeting • EOC established; conducted with virtual participants 18:00 • First SITREP issued	- Council - Reconstruction Authority - NSWPF (SEOCON/REOCON/LEOCON) - LEMC - REOCON - DPE Water - NSWPF (Lead: REOCON) - DPE - DPI - WaterNSW - Council - Fire and Rescue NSW (FRNSW) - NSW Health - EPA
MAR 19	• Daily Central Darling Shire EOC briefings begin • EOC decision to start to remove fish • Community meeting organised for 21 March • Additional chlorine added to water treatment process • NSW Cabinet/Shadow Cabinet briefed • NSW Police Community update	- EOC - Essential Water - REOCON - PIFA
MAR 20	• NSW Health Local Health District (LHD) EOC participation (Local Health District representative) • Fish disposal location found by LEMC, letter provided by EPA of process • South Australian specialist resource identified, although noted that is unavailable at this stage • Bulk water carting begins; contractor engagement	- EOC: NSW Health - EPA - Council - EOC - Council
MAR 21	• Aboriginal Affairs EOC participation • First Town Hall community session; primary concerns over drinking water quality, length of response, lack of monitoring and water use from the river • EPA investigating the fish kill event as possibly 'water pollution'; water sampling undertaken • FRNSW and contractors begin fish removal process • NSW Police Community update	- EOC: Aboriginal Affairs - EOC - EPA - WaterNSW (sample collection) - FRNSW - EOC - PIFA
MAR 22	• NSW Police Community update	- PIFA
MAR 23	• NSW Health media release statements to not use untreated river water for domestic purposes • DPI and OzFish relocate fish in distress • Fish disposal in local waste facility • Wentworth LEMC advised of low DO at Pooncarie	- NSW Health - DPI - OzFish Unlimited (organisation) - Council - EOC - Wentworth LEMC
MAR 24	• Second Town Hall community information session; primary concerns from previous meetings reiterated including length of response collection of dead fish, drinking water quality • DPE Water Community Update: response to community concerns regarding March Menindee fish kills • NSW Police Community update • NPWS bought into EOC due to impacts on native animals • Wentworth Extraordinary EOC held (next meeting: 28 March) based on downriver consequences of Menindee event	- EOC - DPE Water - PIFA - NPWS - LEOC (Wentworth) - EOC
MAR 25	• Printed community newsletters available from the Council community service centre in Menindee • NSW Health begin planning for additional mental health support • Decision to close Menindee EOC on 31 March 2023	- Council - NSW Health - EOC
MAR 26	• To date, 3 tonne of dead fish removed; community express concern over removal/disposal of dead fish • Child presents to Menindee Health services with unexplained rash, concern related to river water; subsequently conclude not related (27 March)	- EOC - NSW Health
MAR 27	• LLS/DPI investigate if river water is suitable for stock • Reports of contaminated water samples near Coombes Transport, Menindee, being investigated by WaterNSW; water samples taken • FRNSW removing booms for river • Winding down of emergency operations	- LLS - DPI - WaterNSW - FRNSW - EOC
MAR 28	• Improvement in DO at Menindee • 5.5 tonnes of dead fish removed to date; DPI analysing fish samples • PIFA combining information on drinking water and river water to reduce confusion • EPA water testing preliminary results; showed potentially toxic algae levels and no pesticides • In winding down Menindee/Central Darling Shire EOC, key stakeholders will transition to Wentworth LEOC	- WaterNSW - DPI - PIFA - Council - FRNSW - EPA - EOC - LEOC (Wentworth)
MAR 29	• EPA water testing analysis information printed and displayed at Police Station and local shop • NSW Premier, MP's and other VIPS address media and attend the affected areas	- EPA - NSW Government officials
MAR 30	• First Nations community groups meeting (at 09:00); primary concerns were the lack of local representation, river water quality and dam levels • Third Town Hall community information session (at 10:00); primary concerns from previous meetings reiterated, including over accountability for the event, future planning and commercial use of water upstream • Central Darling Shire LEOC to return to monitoring status at 08:00 on 31 March 2023 • NSW Police Community update	- EOC - EOC - EOC - PIFA
MAR 31	• EOC stood down; Central Darling Shire LEOC returned to monitoring status; Central Darling Shire EOC daily briefings end • Wentworth EOC briefing; LEOC stood up to alert status • DPE Water Community Update: standing down of the Menindee EOC • DPE Water Community Update: FAQ and water quality update for Wentworth Shire Council residents	- EOC - LEOC (Wentworth) - DPE Water - DPE Water
APR 05	• Wentworth EOC returned to monitoring status • NSW Police Community update	- LEOC (Wentworth) - PIFA
APR 06	• DPE Water Community Update: ongoing sampling regime FAQ	- DPE Water

Figure 31: Timeline of the emergency management response to the March 2023 event. Note the formation and dissolution of the EOC in Menindee. *Source: OCSE*

5.2.1 Need for better coordination and planning

Although observations and monitoring data showed the potential for reduced water quality before the March 2023 event, there was a clear disconnect between agencies responsible for water operations and those responsible for the emergency response.

From October 2022, water management agencies were on heightened alert for fish death events due to poor environmental conditions including flooding and floodplain inundation in the northern Barwon-Darling basin. DPI identified approximately nine fish death events of varying scales (from tens to thousands) in the Menindee region from October 2022 to March 2023.[173]

This led to the formation of the Hypoxic Blackwater Working Group (HBWG) and the WaterNSW Incident Management Team (IMT) for the region (under the Extreme Events Policy).[174] However, the practical impact of the formation of these groups in shaping the emergency response for the March 2023 event is unclear. For example, in the days preceding the March 2023 event, the HBWG identified a DO measurement of below 2mg/L (a threshold value for low DO conditions). This triggered water flow actions by water management agencies. Emergency preparation actions taken as a result of these measurements or how they informed any form of early EM response remain unclear. Feedback to the Review indicated there was no communication with the LEMC or the LEOCON/REOCON (including contacting other agencies). Similarly, the HBWG provided daily water quality updates to the EOC (once established), although it is unclear how this information was then acted upon.

Improving links and communications between water management groups (HBWG and WaterNSW IMT) and emergency management (the LEMC/EOC) is critical, particularly in the transition towards an emergency response. Similarly, the coordination of monitoring and other efforts is key to informing early assessments for emergency operations. Once the EOC was established, there was increased visibility of the responsibilities of each agency in the emergency response (Figure 32).

The understanding of roles and responsibilities, lines of communication and triggers or thresholds for action need to be clearly established well before events. This includes clear lines of communication with the local community to enable their on-ground observations to be channelled into the responsible agency.

Sources of delay included an initial lack of understanding of EM arrangements by some of the key stakeholders. The significant flooding upstream and around Menindee from October 2022 did not result in the declaration of an emergency (such as a natural disaster), which also hampered some responses.[175] Finally, there is currently no nominated 'combat agency' within the EM arrangements for mass fish death events. As a result, the responsibility to coordinate a response falls to the EOCON. This contributed to delays, due to confusion around agency responsibilities and funding streams that could be leveraged to respond to the emergency situation.

This was compounded by a lack of understanding of the EMPLAN provisions and EOC process in the regional bodies and agency representatives and the cost and reimbursement process for both the response and recovery phases of EM.[176]

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173 NSW Department of Primary Industries (2023). Fish Kills in NSW.

174 NSW Department of Environment (2023). Extreme Events Policy: Policy framework for the management of NSW water resources during extreme events.

175 For example, the Reconstruction Authority was limited in its response due to their legislation limiting their response to a Natural Disaster (and associated secondary impacts) only.

176 The Review understands that there was no impact from the NSW Government Election process, as the March fish death event coincided with the Caretaker period (beginning 3 March 2023) and Election (held 25 March 2023). The REOCON undertook verbal discussions with the Minister for Police (and other Cabinet Ministers including Ministers for Water, Agriculture and Emergency Services) and the Shadow Cabinet. The Review notes that this is entirely appropriate in a caretaker Government. DPI was informed of the fish death event on 17 March 2023 and advised the SEOCON that the (then) Minister for Lands and Water had instructed WaterNSW to lead the response to the fish death event. However, this was never formalised and communicated.

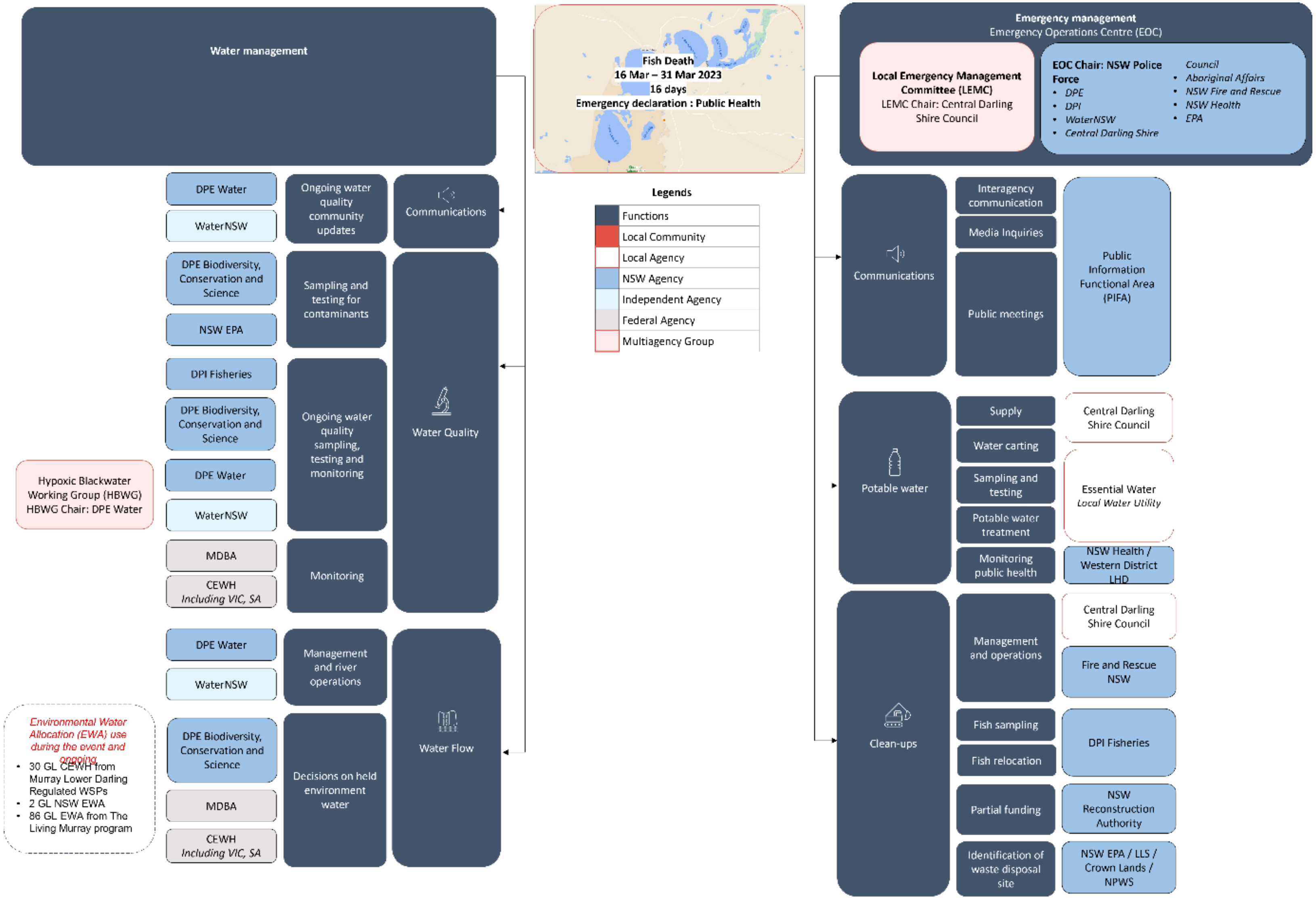

Figure 32: Water and emergency management responsibilities. Agencies responsibility in water management (left) and in the EM response to the March 2023 event (right). *Source: OCSE*

5.2.2 Emergency response triggers

The assumption throughout the emergency situation was that a hypoxic blackwater event was responsible for the fish deaths. While the Review understands that this assumption was reasonable and consistent with available (if limited) data and based on the monitoring undertaken by the water management groups (including the HBWG and WaterNSW IMT), it is not clear how this was arrived at without assessing other potential scenarios (i.e. toxicity, disease, pathogen, etc.) in a robust manner or how this was then communicated to the community. This caused additional community confusion, particularly as the EOC was established based on the basis of a public health response due to concerns over water quality.

The EPA investigated a possible 'water pollution' incident, based on the broad definition of 'pollution' within the Protection of the Environment Act (2022), as the blackwater induced a change in the physical and/or biological properties of the river.

Water sampling, via WaterNSW, was performed by the EPA to investigate heavy metals, pesticides and other chemicals (testing forover 600 analytes). The raw data, analysis and summary were subsequently provided to the community at key locations (e.g. the local shop, Police station, hotels) in hardcopy form. The Review notes sampling was undertaken days after the EOC was established, and due to the nature of the testing there was a lag time period until these results were available and the data made public. This was not communicated to the local community, which heightened concerns (see Section 5.2.7).

Delays were also apparent in other aspects of the emergency response. Removal of carcasses in the immediate term (~72 hours after a fish death event) is critical. After this point, dead fish begin to sink and/or decompose at greater rates. There were no pre-identified sites for disposal of fish carcasses, which impacted the immediate fish disposal process. Locating a site took time and was subject to a number of queries, not least of which was the availability of Council resources (excavators, trucks, etc.). The EPA certified the fish deaths were not a result of a toxicity event, which further reduced the number of site-specific requirements for disposal.

5.2.3 Establishment of the Emergency Operations Centre

The EOC was formerly established on the third day of visible fish deaths in Menindee as a public health response relating to concerns over the supply of safe drinking water to the Menindee township and neighbouring residents. Once the EOC was established under the LEOCON/REOCON, the emergency response was more coordinated. The Review considers the establishment of an EOC was an appropriate response within the existing Emergency Management Framework, given the scale of the fish death event, the significant coordination required between responding agencies and the risk to human health via reduced water quality.[177] Overall, the EOC worked well once established in Menindee and once agencies understood its role and functions. NSW Police provided increased structure and coordination to the response.

The hybrid EOC (with physical and virtual participants) is also considered appropriate by the Review, in that it allowed for a faster and more streamlined response (once established) given the rural remote location. However, there was not an initial widespread understanding of the EOC process until NSW Police took control. Agencies were bought in as information came to the fore. For example, there were delays in bringing in NSW Health, Aboriginal Affairs and NPWS into the EOC, although they played key roles in the response and communicating with the community. This is also reflective of a struggling LEMC within the Central Darling region and the nature of the rural remote location, where not all agencies have a strong presence.

5.2.4 Develop a NSW Mass Fish Death Sub-Plan

A NSW Mass Fish Death Sub-Plan (the Sub-Plan) is therefore recommended. It would be activated when there is a significant community concern (including availability of safe drinking water) or a significant

[177] Under the EMPLAN, where there is no designated Combat Agency or at an agency's request, the responsibility falls to the NSW Police to take control of the response. This leadership was undertaken by the REOCON/LEOCON and done appropriately for this event.

coordinated response required for a fish death event. The Sub-Plan should set out roles and responsibilities of agencies. Although agnostic to the underlying cause of a fish death event, roles would be tailored to causal and other factors (such as subject to other sub- or supporting plans; Appendix 12). The Sub-Plan would allow for a scalable emergency response, with early triggers identified by experts that would activate prevention and planning efforts, with a view to either avoiding or minimising any fish death event. While recognising the need to be both comprehensive yet concise, the Sub-Plan should also have an annexure that focuses specifically on Menindee, given the disproportionate number of events that occur in this region. This would allow specific regional requirements to be outlined to facilitate a scalable local emergency response in the context of resources available through the LEMC and other sources.

The Annexure should also set out the role of agencies and frameworks, such as the HBWG and Water IMT under the Extreme Events Policy and how these interact with the emergency response and include the communications plan (discussed in 5.2.4).

Recommendation 3: Effective emergency management

A local, detailed and effective emergency management framework is required. The current system is dysfunctional and not well understood at the local level. Therefore:

- a NSW Mass Fish Death Sub-Plan, under the Emergency Management Plan NSW (EMPLAN) should be developed and implemented as a matter of urgency (including a specific Menindee appendix)
- a simultaneous assessment of emergency management resources should be undertaken. This includes a review of membership and training; assessment of current prevention and response resourcing, capability and volunteer capacity
- resources should include development of a communications plan and an educational resource package.

Recommendation 3.1

That a NSW Mass Fish Death Sub-Plan is developed as an immediate priority, with a specific annexure dedicated to the Menindee region.

This Sub-Plan should:

- reflect learnings from previous fish deaths across NSW, including locations and frequency.
- include defined triggers that:
  - address the breadth of issues affecting the community e.g. public health, quality of drinking water, disease to fish and animals, water quality measures, etc
  - are consistent with the NSW EMPLAN Prevention, Preparation, Response and Recover (PPRR) framework, with thresholds and levers that can be actioned to prevent or mitigate fish deaths, and interaction with other plans and policies (such as the Extreme Events Policy)
  - consider the future impact of climate change, with particular reference to drought and floods.
- identify the nature of the event, regardless of whether it is under a Natural Disaster and/or subject to another Sub or Supporting Plan and identify the responsibility of each agency (noting that multiple agencies have different responsibilities that may overlap)
- facilitate scalable responses, with consideration of higher-threshold triggers through to actual triggers of a Local and/or actual EOC, ensuring that the key knowledge holders and agencies are informed and there is consistency maintained throughout the emergency process
- include triggers to be considered by the relevant knowledge experts and have the ability for a scalable emergency response, which includes higher-threshold triggers that bring together the relevant knowledge holders (i.e. expert advisory groups, akin to the HBWG but with expanded remit) prior to a fish death occurrence that then informs the emergency process
- that, given the nature of the region, whilst the virtual attendance of expert advisory groups and the LEMC/EOC is appropriate, it is also critical to ensure key positions on-the-ground.
- consider the inclusion of identified health service providers (including Aboriginal health services) as trusted messengers to the community.

Recommendation 3.2

That the NSW Mass Fish Death Sub-Plan, once developed, is exercised by the Central Darling LEMC and NSW Government agencies. Once a NSW Mass Fish Death Sub-Plan is developed, a multi-agency desk top exercise should be undertaken by the LEMC, with support from the REMC as required, to ensure agencies clearly understand their roles and responsibilities and if any amendments need to be made to the Sub-Plan. This exercise will also assist in the development of a communications list for key positions within agencies, that should be updated on an annual basis.

5.2.5 Local Emergency Management Committee membership review

As guided by the SERM Act, LEMC membership usually consists of:

- the General Manager of the Local Government of the relevant local government area as the Chairperson of the Committee
- the Local Emergency Operations Controllers for the relevant local area(s)
- senior representatives of each Emergency Service Organisation operating in the relevant local area(s)
- representatives of Functional Areas where the respective Functional Area representative on the State Emergency Management Committee determines it appropriate and resources permit
- representatives of any other agency or organisation as determined by the LEMC.

The LEMC Chair position is key, as it determines the membership of LEMC for a given emergency, the functional areas that should be present, and who undertakes the formation and operation of the EOC. In the case of Central Darling Shire Council, the Local Emergency Management Officer (LEMO) and LEMC Chair is the General Manager (appointed May 2018). The LEMC Chair and LEMO require a certain level of resourcing and support to function. The current status of the Central Darling Shire Council presents some challenges to this.[178,179,180,181]

LEMC membership should update EM representation and knowledge to ensure optimal functionality. As a matter of urgent priority, EM training should be undertaken by all members of the LEMC and those that would be called upon in an emergency setting (i.e. within an EOC). This will provide further understanding of the EM framework, including lines of communication and escalation patterns (important for a scalable response). There may also be a role for Local Government NSW (LGNSW) to support the LEMC in this training, as a state wide representative body for member councils and the LGNSW's position on the State Emergency Management Committee (SEMC).

Recommendation 3.3

That the REMC, LEMC and NSW Government agencies undertake a review and update the membership of the LEMC, with a view to including appropriate representation (if not already present) from NSW Health (Far West Local Health District), National Parks and Wildlife Service, Crown Lands and/or Local Land Services, and nominated representative from Aboriginal Affairs (and/or local representation). This review should maximise efficiency in membership, facilitating agility and flexibility whilst also ensuring that all the required agencies are represented at an appropriate decision-making level.

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[178] The Council has been in administration since 2013, with implications on its resourcing due to the financial limitations of this status including staffing (~54 FTE as of 2022). *Source:* *ABC News (2023). Central Darling Shire Council's 10-year Administration Under Review by NSW Government.*

[179] The Council has adopted its Long-Term Financial Plan (2023-2032) to ensure its financial sustainability. It is expected to remain in administration until September 2024, although there have been recent announcements that the Minister for Local Government is working towards moving the Council out of administration. *Source:* *Central Darling Shire Council (2022) Annual Report*.

[180] In particular, limited ability to generate sufficient funds, considering the Local Government Area (LGA) covers an area in size similar to Tasmania (~53,000km^2) and supports a population of less than 1,900. *Source:* *Central Darling Shire Council (2022) Annual Report*.

[181] For example, the Review notes that the Council is highly reliant on 'grants and contributions revenue' which in 2021-22 accounted for ~$31 m (~56% of the total income to Council). *Source:* *Central Darling Shire Council (2022) Annual Report*.

Recommendation 3.4

Emergency Management training is undertaken by agencies involved in the LEMC and any EOC that may arise from a mass fish death scenario.

The recommended minimum training (administered and offered by NSW Premiers Department) is:

- Emergency Management overview (1 x 40-minute module), noting that it is a prerequisite for all other courses.
- Introduction to Emergency Management (1 day face-to-face)
- Emergency Operations Centre Concepts (1 day face-to-face)
- General Managers should also consider undertaking the Local Emergency Management Committee Foundations Course (4 x 20-minute modules).

5.2.6 Review emergency response resourcing and capability

Varying levels of knowledge of the EM framework led to a response that was uncoordinated and iteratively progressed throughout the emergency situation. As a result, there were delays getting the right resources to the right places.

A lack of available resources to respond to the March 2023 event also contributed to the delays. This was despite an Expression of Interest process conducted after the 2018/19 fish death events. Crucially, this list was not maintained by any agency. For example, the need for a specialist inland-river boat resource was identified from this list that could have been used for the March 2023 clean-up process. Although located in South Australia, the primary challenge was the operator's absence and that there was no procurement plan and/or other provisions in place that would have ensured this asset was available for deployment. The Review understands that other potential resources were not keen to assist given they had not been previously compensated for the financial burden of providing assistance during the 2018/19 clean-up process.

This lack of pre-identified resource availability or a pre-planned fish disposal process meant only a small fraction of the fish that died in the March 2023 event were removed (approximately 10 of the estimated 15,000+ tonnes of fish carcasses were collected in five days).[182] Further, this was mostly achieved after the critical 72-hour timeframe after which the dead fish begin to sink and/or decompose at increased rates.[183] There was limited communication to the community on the actions taken to deal with the fish collection and disposal, which increased their concern about water quality. Further, local knowledge regarding appropriate sites for collecting dead fish was not considered.

As an immediate action the Council and LEMC, with support from NSW Government agencies, should identify available resources that can be mobilised quickly to dispose of fish carcasses in future. This should include pre-identified sites for disposal under any scenario (toxicity, pollution, disease, etc.) on the various possible land tenures (Crown Lands, Council lands, etc.). Assets and equipment that could be leveraged including their activation timeframes should be included. Once identified through a procurement process, contracts should be put in place that would allow resources to be rapidly called upon in an emergency situation.[184] This procurement process should be updated on an annual basis. In the interim, contractual

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[182] Quantity removed statistic from Pers comm (2023) NSW Police after action review. Total fish death tonnage estimation as expressed in the Baldwin submission.

[183] Noted by several Review submissions.

[184] The NSW RFS have a good centralised system that could be considered for use in this procurement process: ARENA and ARENA HP, which for the RFS encompasses aircraft resources (ARENA) and heavy plant and equipment (ARENA HP) on annual contracts that can be deployed to emergencies.

arrangements and funding for assets that may be needed in the short term should be put in place before the assessment and procurement is complete.[185]

Although there are defined roles assigned to agencies, a resource capability assessment of emergency services should be undertaken to accurately understand agencies' resources, capabilities and capacities in this region, at both a local and regional scale (i.e. across the broader Far West, with consideration given to time-to-deployment).

It was also clear from community consultations that there are volunteer assets that could be and, at the time, wanted to be used. This was echoed in the media, where members of the community suggested that they were not '*being granted meaningful involvement or reassurances*'.[186] The Review was told there were other resources within the community that could be potentially utilised in future events, such as water assets and vehicles.

It is understood the NSW Premier's Department is developing a toolkit that provides guidance for LEMCs, with a component reviewing the deployment of 'spontaneous volunteers'. It would be appropriate to test the toolkit once developed. The SEMC and LEMC should consider Menindee a key test site for this new toolkit.

Multiple organisations have expressed concerndecadess about the engagement and coordination of volunteers that aren't affiliated with an organisation, particularly when it comes to WHS considerations and liability. The *Review of Emergency Services Volunteering*, also being led by the Premier's Department, is considering what changes might be required to better integrate spontaneous volunteers into the EM framework.[187] This Review is also considering legal implications, particularly around Workplace Health and Safety (WHS).

In order to ensure the recommendations within the EM framework are appropriately actioned, the Capability Development Sub-Committee (CDSC) of the SEMC is to be provided a copy of the Report for oversight, with half-yearly reporting to the CDSC on progress of recommendations by the LEMC and NSW Government agencies encouraged.

Recommendation 3.5

That the LEMC and NSW Government agencies involved in any emergency response undertake a resource review. This would include examining and streamlining the tender/standing procurement process, with contractual arrangements in place to cover future events. This should be reviewed on an annual basis.

- As an immediate action, those assets identified in the March 2023 event should be contracted until this more thorough procurement is concluded.
- This should also include pre-identification and potential pre-positioning of resources and disposal sites that can be utilised under different fish death event scenarios and consider the process (including funding arrangements) for water carting in future events.

[185] For example, water carting services that can service affected residents in the scenario of any actual or perceived issue to water quality, and provide a funding mechanism for this. The Review understands that water carting is still occurring to date for some residents in the Menindee weir pool. Proactive water carting is an important learning from the 2018/19 fish death events, where many residents along the Darling-Baarka relied upon volunteer organisations to provide either safe drinking water or the equipment to attain fresh drinking water (such as rainwater tanks or water purifiers).

[186] The Guardian (2023). Menindee Residents ask Official to Drink Town's Water as Reassurance After Massive Fish Kill.

[187] NSW Government (2023). Have Your Say: Better support for our volunteers.

Recommendation 3.6
That the relevant agencies and the LEMC, with support from the REMC, undertake a resource capability assessment of emergency services in this remote area (Menindee) to have a true and accurate picture of the available resources and an understanding of their capabilities.

Recommendation 3.7
Once developed, the SEMC and LEMC should consider Menindee as a key location in which to test the new Local Emergency Management Toolkit.

Recommendation 3.8
That the Capability Development Sub-Committee (CDSC) of the State Emergency Management Committee (SEMC) has oversight of the implementation of the emergency management recommendations of the Review and is provided with half-yearly progress reports.

5.2.7 Need for Improved communications and education

Stakeholders mentioned varying levels of communications success during and after the March 2023 event. Once the EOC was established, communication was coordinated by the Public Information Functional Area (PIFA) under NSW Police, with updates provided by DPE-Water (Appendix 13), NSW Health and the EPA. The Council also provided information via its website, social media, the electronic sign at Menindee Civic Centre, and by locally distributing printed material.[188] It was noted from submissions that, from an agency and LEMC perspective, this avoided community confusion when information was coming from a singular source.

Three community town hall sessions were held on 21, 24 and 30 March 2023, with representatives present from the EOC (including NSW Police, the DPE-Water, WaterNSW, Essential Water, EPA and the Council). A further session was held with Aboriginal representatives on 30 March 2023 to address any specific concerns held by the local Aboriginal community. These sessions were for members of the EOC to address community concerns, with the following key concerns raised in these sessions: drinking water quality, the length of response, disposal of fish, lack of monitoring, water use from the river (including for use on properties and commercial use of water upstream), accountability for the event and future planning.

The Review also heard from other community submissions and consultations that Agency communication efforts did not successfully reach target audiences or impart the information that was wanted. Community members also stated the various water and EM authorities did not listen to them and underappreciated or underutilised their significant local knowledge of the river and country.

Particular issues noted included the

- availability and access to information (e.g. many updates were only available via internet in an area with low internet access)
- sporadic nature of information and information sessions
- limited content of some of the information.

Further, despite PIFA acting as the EOC communication coordinator, there was no collation of information from all the various government agencies into a single package for dissemination to the community, which resulted in a disjointed understanding of the available information. This led to community concern that there was not a 'one government' approach to the emergency situation. It was not until 28 March 2023 (nine days after the EOC was established) that PIFA addressed this by starting to collate agency information.

[188] Central Darling Shire Council Pers Comm 21 Aug 2023.

Submissions and community consultations also indicated that the explanations provided to the community about the causes of the fish death event required improvement and further discussion. Community concerns stemmed from a lack of presentation of alternative hypothesis and data and how sampling was undertaken (including the process and timeframes of collecting and analysing the samples).

The Review did note some positive communications during the March 2023 event. The Menindee Health Service (which provides ongoing medical and mental support to the community in conjunction with specialists from the Maari Ma Aboriginal Health Corporation) was a trusted voice within the community for this event and distributed printed (hard copy) health information. As a trusted voice that has an ongoing presence in the community, there was evidence to suggest that this was well received by the community.

Further, the EPA provided hard copies of a summary analysis of raw data from its sample testing at the local corner shop. While the Review notes this practice of providing key information and raw data at visible community locations, access to this information was not widely communicated to the community and there were community concerns about the length of time and transparency of the sampling and analysis.

A priority action for agencies and organisations during an emergency is to develop an appropriate communications plan for the Menindee region. This communication plan should consider the best methods to effectively and efficiently communicate the collated information of all involved agencies and provide it to all concerned stakeholders in a readily accessible format. It should also include the various methods of providing information and communications materials. Increasing two-way community consultation needs attention. Important observations originated from the community in the March 2023 event, such as the first sightings of fish deaths, that were not obviously taken up by the relevant agencies.

The Review notes efforts by agencies to improve community understanding and provide increased transparency of data and information, but given feedback from consultations, this still requires further focus. Therefore, the communications plan should also be paired with an ongoing targeted education package for the community and other stakeholders in the region.

The proposed education package should proactively outline the science behind phenomena such as hypoxic water and blue-green algae, or any other issue causing community concern. This could include operational matters, such as how an EOC operates and its primary functions. The package could become part of the remit of the expert advisory groups in conjunction with relevant agencies. Delivery models as well as content should be explored, e.g. quarterly town hall information sessions on specific topics paired with hardcopy information sheets.

5.2.8 Other community support

The events of March 2023 will not be the last mass fish death event in this region. Ongoing resourcing and adaptive reviews of mental health services should be considered, with a focus on how best to support Aboriginal and non-Aboriginal communities affected by fish deaths and other natural disasters. The cumulative stress and impacts from multiple disasters and changing environmental conditions is well recognised by community service providers.[189]

How best to communicate the availability of mental health services before, during and after emergency situations, and alternative models of delivery and outreach should be examined. Efforts were made during the March 2023 event to increase the visibility of mental health services, although the Review heard evidence there was little community uptake of these programs.[189] This could be for a number of reasons, including self-referral, stigmatisation (especially within a small community), lack of awareness, financial considerations and other cultural and/or social factors – all of which should be investigated when seeking to improve community mental health and resilience.

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[189] Western NSW Local Health District pers comm 4 Aug 2023.

Outreach efforts and mental health education programs should be a central tenet of any response to and recovery from a fish death event, irrespective of the scale of the event or whether it triggers a formalised emergency response. It is also important that any mental health services fully understand the context of the spiritual and cultural links to the Darling-Baarka River and Country, but also in the livelihoods that are tied directly or indirectly to the quality of the river. The Review notes the ongoing work of the LHD and Maari Ma Aboriginal Health Corporation in this space.

Recommendation 3.9

That the LEMC, with guidance from the REMC and the agencies with responsibility for communicating with the community, jointly develop a communications plan that addresses the regional requirements of the community in the Menindee region, the proactive release of information, and considers better ways to engage with different audiences within the community including community consultation and feedback (i.e. two-way communication).

This communication plan should acknowledge the most appropriate methods for communication, including:

- consistency in information provision: time, locations available, regularity in updates in non-emergency situations (i.e. weekly/fortnightly/monthly) that should be tied to various higher-threshold triggers
- collated information from all agencies, to reduce community confusion and provide comprehensive and aligned messaging.
- methods of communication: in noting that not all residents have equal access to the internet, using sources such as:
    - information sessions with experts
    - trusted voices within the community, such as the local health service
    - local media (radio, TV)
- provision of physical hardcopies of communication packages at key locations are important; for example, the Menindee Health Service, Police Station, Council (and utilising the Council's electronic sign), Men's Shed, etc.
- engaging with local Aboriginal groups and Elders to disseminate information amongst the community.
- development of pre-planned and agreed upon (by the relevant agencies) information packages that can be deployed as a proactive measure as required, such as prior to and during an emergency situation and provision of the latest real-time monitoring data, including explanation of timeframes for analysis.

Recommendation 3.10

Develop an education package for the impacts of fish deaths in regional and remote communities in NSW, that outlines the current science on possible triggers (such as blackwater and hypoxic events) and the groups that are involved in the monitoring and/or response.

6. Detailed Recommendations

The following include high level and detailed recommendations made in this report. The recommendations follow the order set out in the Executive Summary released on 31 August 2023.

A lead agency should be clearly tasked with responsibility and oversight for implementation and reporting progress against the recommendations contained in this report.

Recommendation 1: Regulatory environmental protections must be enforced

The regulatory framework must be upgraded to include legally enforceable obligations and powers to give effect to environmental protections and whole of catchment ecosystem health, as expressed in the objects of water, environmental and biodiversity legislation.

Changes should:

- draw on scientific, cultural and local community insights and be developed in partnership with these knowledge communities
- address risks to the Lower Darling-Baaka and its water-dependent ecosystems
- be informed by an independent review of existing water rights, water accounting systems, exercise of rules and operational parameters, and their impact on riverine catchment health. This includes provisions in Water Sharing Plans to improve water flow across the system
- be based on much improved real-time data and monitoring of the whole river system.

Recommendation 1.1

Ensure the newly convened Connectivity Expert Panel examines the adequacy of rules in all northern Basin water sharing plans (regulated and unregulated) in contributing to hydrological connectivity with the Lower Darling-Baaka River and southern Basin.

Recommendation 1.2

Prioritise changes to water sharing plans in the northern Basin based on findings of the Connectivity Expert Panel, with the intent of improving outcomes through the system including in the Lower Darling-Baaka River.

Recommendation 1.3

Prioritise the review of the Water Sharing Plan for the Murray and Lower Darling Regulated River Water Sources 2016 with a focus on the adequacy of Plan provisions for meeting environmental and water quality objectives.

Recommendation 1.4

Explore the extension of existing provisions for water releases when the lakes are under the direction of the MDBA that are currently only available when the combined volume of Menindee lakes is below 480GL.

Recommendation 1.5

In consultation with the MDBA, explore how the management of Menindee Lakes as a shared inter-jurisdictional resource can be better managed to mitigate water quality and fish deaths in Weir 32 weir pool (or Menindee weir pool).

Recommendation 1.6

Develop triggers for when water is to be delivered from the upper lakes into Weir 32 weir pool (or Menindee weir pool) for mitigating water quality issues and the risk of mass fish deaths recurrence.

Recommendation 1.7

Review the risk assessment and mitigation strategies for managing low dissolved oxygen included in the Murray and Lower Darling Water Quality Management Plan to reflect water quality issues and mass fish deaths observed in 2018-19 and 2022-23.

Recommendation 2: Better decisions require better data

An integrated, open, whole-of-system approach to data collection, analysis and management needs to be established. This is essential to enable timely and transparent decision making and build trust in the community. This water data regime should be based on the following principles:

- the data must cover the whole of the river system as all parts are connected. The monitoring network needs to be expanded to address key gaps (e.g. sites, resolution, and indicators)
- the data must minimally cover water flow rates and water quality (including dissolved oxygen), fish and algal biomass, and monitoring cause and effect variables to provide early warning of deteriorating conditions and ecosystem response
- the data must be open and accessible to all (Findable, Accessible, Interoperable, and Reusable – FAIR).
- investment in new sensors and technology platforms (including telemetry), and their maintenance, to provide adequate coverage and warning
- development and use of probabilistic models and baseline steps towards a catchment digital twin, drawing on real time data, machine learning algorithms and insights
- recognition and integration of community observations and Aboriginal Knowledge as important sources of evidence.

Recommendation 2.1

A NSW (state-wide) water quality and monitoring strategy, implemented within 12 months, which is publicly available and updated regularly, including quarterly progress reports on its development. The strategy should encompass or be linked to:

- an early warning system drawing on improved monitoring and modelling and a plan to activate strategies to mitigate fish death events
- an evaluation and adaptive learning program informed by improved real-time data, modelling and assessment of the effectiveness of interventions to improve water quality and system health and resilience.

Recommendation 2.2

Accelerate the work program for installing dissolved oxygen sensors in high-risk areas, particularly the Lower Darling-Baaka where several major fish death events have occurred in recent years.

Recommendation 3: Effective emergency management

A local, detailed and effective emergency management framework is required. The current system is dysfunctional and not well understood at the local level. Therefore:

- a NSW Mass Fish Death Sub-Plan, under the Emergency Management Plan NSW (EMPLAN) should be developed and implemented as a matter of urgency (including a specific Menindee appendix)
- a simultaneous assessment of emergency management resources should be undertaken. This includes a review of membership and training; assessment of current prevention and response resourcing, capability and volunteer capacity
- resources should include development of a communications plan and an educational resource package.

Recommendation 3.1

That a NSW Mass Fish Death Sub-Plan is developed as an immediate priority, with a specific annexure dedicated to the Menindee region.

This Sub-Plan should:

- reflect learnings from previous fish deaths across NSW, including locations and frequency.
- include defined triggers that:
    - address the breadth of issues affecting the community e.g. public health, quality of drinking water, disease to fish and animals, water quality measures, etc
    - are consistent with the NSW EMPLAN Prevention, Preparation, Response and Recover (PPRR) framework, with thresholds and levers that can be actioned to prevent or mitigate fish deaths, and interaction with other plans and policies (such as the Extreme Events Policy)

  - consider the future impact of climate change, with particular reference to drought and floods.

- identify the nature of the event, regardless of whether it is under a Natural Disaster and/or subject to another Sub or Supporting Plan and identify the responsibility of each agency (noting that multiple agencies have different responsibilities that may overlap)
- facilitate scalable responses, with consideration of higher-threshold triggers through to actual triggers of a Local and/or actual EOC, ensuring that the key knowledge holders and agencies are informed and there is consistency maintained throughout the emergency process
- include triggers to be considered by the relevant knowledge experts and have the ability for a scalable emergency response, which includes higher-threshold triggers that bring together the relevant knowledge holders (i.e. expert advisory groups, akin to the HBWG but with expanded remit) prior to a fish death occurrence that then informs the emergency process
- that, given the nature of the region, whilst the virtual attendance of expert advisory groups and the LEMC/EOC is appropriate, it is also critical to ensure key positions on-the-ground.
- consider the inclusion of identified health service providers (including Aboriginal health services) as trusted messengers to the community.

Recommendation 3.2

That the NSW Mass Fish Death Sub-Plan, once developed, is exercised by the Central Darling LEMC and NSW Government agencies. Once a NSW Mass Fish Death Sub-Plan is developed, a multi-agency desk top exercise should be undertaken by the LEMC, with support from the REMC as required, to ensure agencies clearly understand their roles and responsibilities and if any amendments need to be made to the Sub-Plan. This exercise will also assist in the development of a communications list for key positions within agencies, that should be updated on an annual basis.

Recommendation 3.3

That the REMC, LEMC and NSW Government agencies undertake a review and update the membership of the LEMC, with a view to including appropriate representation (if not already present) from NSW Health (Far West Local Health District), National Parks and Wildlife Service, Crown Lands and/or Local Land Services, and nominated representative from Aboriginal Affairs (and/or local representation). This review should maximise efficiency in membership, facilitating agility and flexibility whilst also ensuring that all the required agencies are represented at an appropriate decision-making level.

Recommendation 3.4

Emergency Management training is undertaken by agencies involved in the LEMC and any EOC that may arise from a mass fish death scenario.

The recommended minimum training (administered and offered by NSW Premiers Department) is:

- Emergency Management overview (1 x 40-minute module), noting that it is a prerequisite for all other courses.
- Introduction to Emergency Management (1 day face-to-face)
- Emergency Operations Centre Concepts (1 day face-to-face)
- General Managers should also consider undertaking the Local Emergency Management Committee Foundations Course (4 x 20-minute modules)

Recommendation 3.5

That the LEMC and NSW Government agencies involved in any emergency response undertake a resource review. This would include examining and streamlining the tender/standing procurement process, with contractual arrangements in place to cover future events. This should be reviewed on an annual basis.

- As an immediate action, an immediate action, those assets identified in the March 2023 event should be contracted until this more thorough procurement is concluded.
- This should also include pre-identification and potential pre-positioning of resources and disposal sites that can be utilised under different fish death event scenarios and consider the process (including funding arrangements) for water carting in future events.

Recommendation 3.6
That the relevant agencies and the LEMC, with support from the REMC, undertake a resource capability assessment of emergency services in this remote area (Menindee) to have a true and accurate picture of the available resources, and an understanding of their capabilities.

Recommendation 3.7
Once developed, the SEMC and LEMC should consider Menindee as a key location in which to test the new Local Emergency Management Toolkit.

Recommendation 3.8
That the Capability Development Sub-Committee (CDSC) of the State Emergency Management Committee (SEMC) has oversight of the implementation of the emergency management recommendations of the Review and is provided with half-yearly progress reports.

Recommendation 3.9
That the LEMC, with guidance from the REMC and the agencies with responsibility for communicating with the community, jointly develop a communications plan that addresses the regional requirements of the community in the Menindee region, the proactive release of information, and considers better ways to engage with different audiences within the community including community consultation and feedback (i.e. two-way communication).

This communication plan should acknowledge the most appropriate methods for communication, including:

- consistency in information provision: time, locations available, regularity in updates in non-emergency situations (i.e. weekly/fortnightly/monthly) that should be tied to various higher-threshold triggers
- collated information from all agencies, to reduce community confusion and provide comprehensive and aligned messaging.
- methods of communication: in noting that not all residents have equal access to the internet, using sources such as:
  - information sessions with experts
  - trusted voices within the community, such as the local health service
  - local media (radio, TV)
- provision of physical hardcopies of communication packages at key locations are important; for example, the Menindee Health Service, Police Station, Council (and utilising the Council's electronic sign), Men's Shed, etc.
- engaging with local Aboriginal groups and Elders to disseminate information amongst the community.
- development of pre-planned and agreed upon (by the relevant agencies) information packages that can be deployed as a proactive measure as required, such as prior to and during an emergency situation and provision of the latest real-time monitoring data, including explanation of timeframes for analysis.

Recommendation 3.10
Develop an education package for the impacts of fish deaths in regional and remote communities in NSW, that outlines the current science on possible triggers (such as blackwater and hypoxic events) and the groups that are involved in the monitoring and/or response.

Recommendation 4: Interventions to mitigate against future mass fish deaths
An integrated suite of strategies should be designed and implemented to reduce the risk of further mass fish deaths and restore the health of the broader river ecosystem. These strategies should include improved monitoring, data collection and sharing, and be integrated with other recommendations in this report. The strategies should ensure risks are identified and managed, impacts quantified and adaptive learning implemented. These interventions should at least include:

Immediate term measures (0-12 months)

Immediate measures to manage water quality should focus on maintaining dissolved oxygen in the Menindee weir pool. Potential interventions include:

- modifying the nature of environmental and other water releases (such as pulsing releases) to maximise desired benefits
- pumping/recirculation infrastructure to enable water release from Pamamaroo outlet without exhausting environmental water holdings
- investigating the feasibility of oxygenation infrastructure to maintain refugia in designated areas
- reducing oxygen demand in the Menindee weir pool by reducing biomass - including fish removal (especially carp) and suppression of algal growth
- applying short-term technical fish passage solutions to create temporary opportunities for fish to progress upstream

Mid-term strategies (1-5 years)

- Construction of fishways identified in the NSW Fish Passage Strategy, focusing on priority Menindee Lakes sites for fishways. Priority and resourcing should be given to the construction of effective fishways to maximise fish mobility above the Menindee weir pool. Specifically, movement between Lakes Wetherell. Pamamaroo and Menindee, and the Darling River below Weir 32. These fishways should be designed in consultation with the local community, consider cultural knowledge and address the specific needs of the location.
- An integrated national invasive fish species management strategy be finalised and resourced, including physical, biological and chemical controls. Implementation of the strategy should be accompanied by an information, communication and education plan, informed by local and Aboriginal knowledge, and subject to monitoring and annual reporting of actions, impacts and adaptive management responses.
- Work with other states and territories to consider the National Carp Control Program (NCCP) and deployment of the carp virus, including how to manage the uncertainties (biomass estimates, potential for genetic resistance, herd immunity, latency and recrudescence).

Long-term strategies (ongoing)

- Restoration of flow regimes and connectivity across the catchment
- Water quality – accounting and management of nutrient inflows across the catchment
- Coordinated and systemic ecosystem regeneration strategies, inclusion of Aboriginal people's knowledge, including R&D and scale up of refugia for fish, invertebrate and other species
- In addition to other performance and impact metrics, the strategy should include monitoring of iconic long-lived animal, plant and invertebrate species recognised for their contribution to river health, including species identified as culturally significant to Indigenous communities.

Recommendation 4.1: Short, medium and long-term fish passage solutions are implemented

Immediate actions (0-12 months)

- Install temporary fish passage solutions that can be rapidly retrofitted to the site. Temporary fish passages from Finland and a recently prototyped new tube design show promise, but are presently untested in Australian conditions. Any immediate measure considered would need to be installed by December 2023. This would require rapid scoping and design, and assurances that installation could be progressed provided funding and approvals were rapidly secured, as an experimental pilot. Ideally, a comparative trial of both designs would be implemented and rigorously assessed in the coming season to determine whether their long-term deployment would represent effective mitigation measures
- Design and implement a "trap and transport" program in partnership with local communities and/or indigenous ranger groups. Trap and transport systems involve the physical capture and relocation of fish over a barrier. In early 2019, DPI Fisheries trapped and relocated 20 stressed Murray cod from a pool downstream of Weir 32. At Menindee this would require the regular movement of fish "accumulating" downstream of Pamamaroo outlet or Menindee Main Weir and release into upstream

sections. It would require an investment of resources and training to ensure fish safety and minimise stress during handling

- Monitor water quality and subsequently close fish passages at Burtundy, Pooncarie and Weir 32 at low levels of dissolved oxygen. The closure of these fish passages would prevent the further concentration of fish into the impacted zone
- Accelerate and implement modifications to existing Burtundy, Pooncarie and Weir 32 fishways. Both the MDB Native Fish Strategy and the NSW Fish Passage strategy note that existing fish passage solutions at Burtundy, Pooncarie and Weir 32 are sub-optimal designs that require modifications to improve operations over a wider range of flows. Further, these designs do not take into account Traditional Aboriginal knowledge or cultural considerations
- Publicly release results of the temporary fish passage pilot at Pamamaroo inlet.
- Develop a detailed, stand-alone business case for fishways at Menindee Lakes and at the high priority sites to enable funding to be considered separate to broader works or larger programs that are often beset by implementation delays

Mid-term actions (1-2 years)

Investigate (through detailed engineering designs) permanent fish passage solutions for the Pamamaroo outlet and inlet and the Menindee Main Weir/Wetherell outlet:

- Lake Pamamaroo outlet and inlet: this solution would allow fish to migrate upstream into Lake Pamamaroo and downstream, to complete the connection to the Darling-Baaka.
- Menindee main weir: This site is problematic as it serves to act as an overflow weir and does not constantly release water under current operating rules. Provision of passage at this location would require an operational rule change to facilitate flows more frequently. As this site also contains sluice gates, which are harmful to fish, the installation of an overflow LayFlat gate would be required to provide adequate upstream and downstream pathways.

Long-term actions (3-5 years)

Implement a long-term program with local communities and indigenous groups. This would integrate and operationalise the suite of solutions needed to protect fish passage, and water quality, in the Darling-Baaka. Reconnecting the Darling-Baaka will require a long-term commitment, funding and detailed works program. Annual checks should be performed to ensure all implemented solutions are operating efficiently and appropriately and that there are positive changes to fish communities throughout the Lower-mid Darling-Baaka system.

7. APPENDICES

Chief Scientist & Engineer

Independent review into the 2023 fish deaths in the Darling-Baaka River at Menindee

APPENDICES

List of appendices

Chapter 1

1. Terms of reference
2. Expert panel membership
3. Summary of recommendations from previous reviews
4. Site visits and stakeholder meetings
5. List of submissions

Chapter 2

6. Sentinel-2 algae mapping using the WaterNSW-Custom Algae Script in the Mid-Lower Darling
7. Conceptual map
8. Sediment and water analysis

Chapter 3

9. National Carp Control Plan & Carp virus

Chapter 4

10. Emergency management framework

Appendix 1

The NSW Chief Scientist & Engineer (CSE) was asked to undertake an independent review into the February-March fish death event in the Darling-Baaka River at Menindee.

Terms of Reference

In undertaking the Review, the Chief Scientist & Engineer will consider:

1. Likely cause/s of the fish death event, including
    a. Environmental conditions in the lead up to the event
    b. Assessment of relevant monitoring data, including water data, to assist with determining likely causes
    c. Management and sufficiency of water flow at the time of the event.
2. Response to the fish death event, including:
    a. Role of the different agencies/departments when responding to the event
    b. Action taken by agencies/departments (including public health response) and others when responding to the event
    c. Role of the State Emergency Management Framework for responding to the event
    d. Communication with the community during the event, including consultation with First Nations people and organisations.
3. Recommendations should consider:
    a. Monitoring data and other information that can assist with predicting and responding to fish death events
    b. Appropriateness of the response during the event and potential steps/action that could be taken to enhance the effectiveness of future responses (including preparedness, training, communication and collaboration across groups)
    c. Appropriateness of the State Emergency Management Framework to respond to the event
    d. Local or other interventions that should be considered to mitigate or avoid future events
    e. Any other matters that the Chief Scientist & Engineer considers relevant.

Appendix 2

Establishing an expert panel was part of the Review Terms of Reference. Experts were identified through the development of a skills matrix and were selected on the experience required to advise the Review. The expert panel membership included:

Expert Panel membership

- **Dr Darren Saunders** (Chair), NSW Deputy Chief Scientist & Engineer
- **Professor Robert Vertessy**, Principal, Global Change Advisory
- **Professor Lucy Marshall**, Executive Dean, Faculty of Science and Engineering, Macquarie University
- **Professor Lee Baumgartner**, Executive Director, Professor of Fisheries and River Management, Gulbali Research Institute, Charles Sturt University
- **Associate Professor Bradley Moggridge**, Kamilaroi Water Scientist, Associate Professor in Indigenous Water Science. Centre for Applied Water Science, University of Canberra
- **Associate Professor Michael Reid**, Associate Professor in physical geography, Department of Geography and Planning, University of New England
- **Doctor Sarah Mika**, Senior Lecturer in Aquatic Ecology and Management, Aquatic Ecology and Restoration Lab, University of New England

Expert advisor (emergency management)

- **Mr David Owens APM**, Managing Director, Risk-e Business Consultants

Appendix 3

Summary of recommendations from previous reports

The following tables provide a summary of the recommendation from two previous reviews into the fish death events in Menindee in 2019:

- Australian Academy of Science (2019). Investigation of the causes of mass fish kills in the Menindee Region NSW over the summer Of 2018–2019 (referenced in Tables as Academy of Science).
- Vertessy, R., Barma, D., Baumgartner, L., Mitrovic, S., Sheldon, F. and Bond, N (2019). Independent Assessment of the 2018-19 fish deaths in the lower Darling (referenced in Tables as Vertessy)

The recommendations have been grouped with reference to the Chapters in this Report that appear most relevant. There is some-cross over (e.g. improved communications and engagement is relevant to both Chapters 4 and 5 in this report). This summary was considered by both the Review Team and Expert Panel during the Review.

Chapter 3: What should we do in the future?

Recommendation	Source	Page

Recommendation 5: Improve the health of the Darling River, through adequate and effective planning, which is scientifically informed
• Repeal the Northern Basin Amendment decision (70 GL/ year), given:
  ○ insufficient scientific evidence for over-recovery of environmental water
  ○ peer-reviewed scientific evidence of ongoing decline of river ecosystems, including Ramsar-listed wetland sites, and superficial socio-economic analyses not adequately incorporating long-term costs on ecosystem services
  ○ broad community concern, including from Traditional Owners and lower Darling and Menindee communities.
• Improve the capability for prediction of critical events, using satellite-based catchment 'real time' water quality monitoring, focused on improved understanding of dynamics of hydrology and microbial and cyanobacterial populations.
• The Murray-Darling Basin Authority and States should rigorously assess and implement Northern Basin water resource plans to ensure they:
  ○ meet needs of downstream catchments
  ○ align with environmental and water quality objectives of the Basin Plan; and assess the water quality requirements in respect of Indigenous cultural and spiritual values, referring to guidance on values contained in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality
  ○ fully protect environmental flows throughout the Darling
  ○ apply event-based management to meet the full range of ecologically-informed flow targets
  ○ rigorously report, monitor and audit diversions; these must be metered, not just modelled
  ○ incorporate the rights and interests of Aboriginal communities (Indigenous people's values, uses and native title rights), noting that the accreditation process must consider the objectives of Indigenous people in relation to managing the water resources of the water resource plan area and the outcomes for the management of the water resources of the water
	Academy of Science	55

Recommendation	Source	Page
resource plan area that are desired by Indigenous people, as well as cultural flows. • Restore funding to the Sustainable Rivers Audit, including native fish, to improve monitoring and understanding of the metapopulation dynamics of priority species, and enable adaptive management.		
Recommendation 7: Invest to fill high priority knowledge gaps as the MDBP continues to be implemented, and then reviewed in 2026: • Improve capacity for early warning of prolonged cease-to-flow conditions and ecological stress, including water quality and algal status. • Better understand the relationship between land management practices and the quantity and quality of water in the Darling River. • Re-establish comprehensive monitoring (such as the Sustainable Rivers Audit) of the biota and drivers of rivers and wetlands in the Darling River and its tributary river catchments. • Improve prediction of hydrological and ecological responses to climate change. Understanding how climate change impacts on hydrological behaviour and the interaction and responses of vegetation to changing CO_2 concentrations and increasing temperature will be critical. This is essential to development of policy and water management strategies that can deliver ecological wellbeing of our basin rivers under the changes in climate and the changing hydrological and ecological process in our rivers and catchments. • Noting that the research agenda for the Murray-Darling Basin has in recent years been relatively well served by the biophysical sciences, and that the Southern Basin has been more closely studied than the north, we recommend that government agencies and research organisations increase and re-focus their research efforts to meet the water governance and management challenges outlined here. We also note that there has been an overall decline in funding for water research in the past decade with the loss of key agencies that supported integrated natural resource management (NRM) research and participatory methods (e.g. Land and Water Australia, the National Water Commission). There is a clear need for more research to assist Australian society with the transformations that are required to sustainably manage the Darling River and its wider basin. This will require a better understanding of: o models and processes to support adaptation around structural and economic change in the water sector and to climate change ◦◦ collaborative water planning o the processes of institutional change in water organisations o conflict resolution, transparency and legitimacy in public policy decision-making o Indigenous recognition and access to water o stewardship in land and water management, as well as innovations in sustainable livelihoods.	Academy of Science	57
Recommendation 7: NSW should initiate a program to remove barriers to fish movement and enhance mobility through improved passage at existing weirs and regulators.	Vertessy	75

Recommendation	Source	Page
Recommendation 9: Basin governments should initiate a joint program to significantly accelerate river model development to evaluate different Basin policy options.	Vertessy	76
Recommendation 10: Commonwealth and State governments should significantly increase investment in research and development, co-opting the science community, to address long-standing gaps in our knowledge of riverine hydrology and ecology. A priority focus of those new arrangements should be applied research that serves the information needs associated with Basin Plan implementation.	Vertessy	77
Recommendation 11: NSW should continue emergency responses such as the use of aerators and fish translocations, noting that these are short-term emergency measures and may not prevent additional fish death events if adverse conditions persist or re-occur.	Vertessy	77
Recommendation 12: Once the adverse environmental conditions have abated, NSW should undertake monitoring of fish populations in the lower Darling to more fully understand the impacts of the recent fish death events on fish numbers and remaining fish population status.	Vertessy	78
Recommendation 13: NSW and MDBA should jointly undertake a risk assessment to identify parts of the Darling Basin that are most at risk of future fish death events. This information should be used to inform the development of future early warning systems and emergency response plans.	Vertessy	78
Recommendation 16: Basin governments should ensure that the Basin Native Fish Management and Recovery Strategy is adequately resourced and involves authentic collaboration with government water scientists, academics and consultants, local communities and Aboriginal stakeholders. This strategy should build on efforts such as the lapsed Native Fish Strategy and current State programs	Vertessy	79
Recommendation 19: NSW and QLD should introduce more accurate continuous and real-time monitoring of diversions in the Barwon–Darling, to ensure protection of managed connectivity events. Compliance around all metering requirements and overland flow extractions should be strengthened expeditiously.	Vertessy	80
Recommendation 20: NSW and QLD should improve the reliability and transparency of the assessment of the hydrologic impacts of floodplain harvesting.	Vertessy	80
Recommendation 21: The MDBA should continuously update pre-development model runs developed for the Basin Plan with recent climate information to enable more rapid assessment of the effects of diversions and environmental water releases	Vertessy	81
Recommendation 22: Commonwealth and State environmental water managers should cooperate to develop a suitable forecasting tool to support active management of environmental water.	Vertessy	81
Recommendation 23: NSW should initiate a project to establish a "demonstration reach" in the lower Darling, where multiple threats to fisheries recovery are mitigated to create beneficial conditions for long-term fish recovery. This demonstration reach should be a key feature of the Native Fish Management and Recovery Strategy and should heavily involve the local community, including Aboriginal stakeholders.	Vertessy	81
Recommendation 24: Basin governments should ensure that the Native Fish Management and Recovery Strategy includes the appropriate elements of the Murray Cod National Recovery Plan pertaining to fish kills.	Vertessy	81

Recommendation	Source	Page
Recommendation 26: NSW should redress gaps in water quality monitoring (dissolved oxygen, temperature, algae) at high risk sites in the Barwon–Darling. This could include investigating and adopting emerging technologies such as remote sensing, and improving the use of real-time data to support early warning and forecasting	Vertessy	82
Recommendation 27: NSW and QLD should improve monitoring of end-of-system tributary flows that contribute to hydrologic connectivity in the Darling system, and make that data readily available	Vertessy	82

Chapter 4: Governance, policy and operations

Recommendation	Source	Page
Recommendation 1: Within 6 months, take urgent steps to ensure that there is sufficient flow—considering both quality and quantity of water—in the Darling River to prevent stratification and blue-green algal blooms. • At the first substantial natural flow event in the river tributaries, the Commonwealth Environmental Water Holder and states should cooperate to release available environmental water to flush the system, protected by pumping embargos, and lift water levels in upper lakes to above 200 GL. • In the absence of sufficient rainfall in upper catchments, the Commonwealth Environmental Water Holder should consider purchasing additional temporary consumptive (allocations and/or long-term leases) water following assessment of risks of low water quality and cost. • In the interim, use direct oxygenation of weir pools, which could be an effective in a few key refugia. However, this is only a short-term solution until conditions ameliorate. • Implement long-term strategies to increase flows and water quality in the Darling River and its tributary river catchments	Academy of Science	54
Recommendation 2: Within 6 months, establish a Menindee Lakes restoration project, to determine sustainable management and operation of the lakes system and the Lower Darling and Darling Anabranch • Establish a whole-of-government committee (state, federal and water, environment, fisheries), with a local community advisory committee, which includes Indigenous peoples and which reports regularly to the public. • Restore wetting and drying regimes in lakes Menindee and Cawndilla, within Kinchega National Park. • Ensure relevant authorities hold and manage at least 400 GL of usable water reserves, using lakes Pamamaroo and Wetherill, with progression towards an environmental restoration program for the lakes and Lower Darling, including the Darling Anabranch. • Make the required adjustments to sustainable diversion limit estimates, given implementation of restoration of drying and wetting regimes and rigorous estimation of evaporation savings. • Consider any required changes to the interstate Murray-Darling Basin Agreement for operation of Menindee Lakes	Academy of Science	54

Recommendation	Source	Page
Recommendation 3: Initiate a community planning process in the Lower Darling to restore river health and sustain local livelihoods • Establish a Lower Darling Communities rescue plan focused on river health, Menindee Lakes management, livelihoods based on water, customary management practices, and critical human needs (drinking water and sanitation). • Provide structural adjustment funding to affected communities in relation to water recovery and changes to river management to value add for regional communities (supporting Productivity Commission recommendation).	Academy of Science	55
Recommendation 4: Improve meaningful engagement with river-based communities, including Indigenous peoples • Implement the Ministerial Council recommendation to amend the Basin Plan to include Indigenous representation on the Murray-Darling Basin Authority • Improve governance and transparency in Basin water management, including establishing a Northern Connected Basin Environmental Watering Committee, with representation of traditional owners.	Academy of Science	55
Recommendation 6: Return to the intent of the 2012 Murray-Darling Basin Plan to avoid increasing risks of more fish kills and other environmental problems for the Darling River: • Identify and implement legal, policy and operational mechanisms, including 'shepherding arrangements' which protect environmental water throughout the Darling River systems and its tributary river catchments. • Repeal the cap on 1500 GL on water buybacks (Sec 85C of the Water Act 2007) from willing irrigators to recover water at the least cost to taxpayers, and fund additional infrastructure, constraint and supply projects, only where independent reviews find with high confidence that they provide required hydrological, ecological, cultural and economic benefits. • Audit and assess the take of floodplain harvesting on New South Wales and Queensland floodplains, adjusting for commitments to the Murray-Darling Basin Cap and accounting for long-term groundwater impacts, before licensing and regulation. Regulation should be supported by ongoing monitoring and metering. • Reinstate the Murray-Darling Basin Cap of 1995, agreed to by all state and territory governments and the Commonwealth Government. To achieve that outcome an inquiry must be undertaken to specify the levels of take of water at 1993/1994 (NSW, VIC, SA) and 1999/2000 (QLD) levels of water resource development from the river, floodplains and connected groundwater systems, affecting flows into the Darling river. • Implement regulation of floodplain harvesting across New South Wales and Queensland, incorporating understanding of assessment of take at Murray-Darling Basin Cap levels and accounting for long-term groundwater impacts. • Implement rigorous water accounting across the Northern Basin, applied to all recovery through supply, infrastructure (e.g. increasing volume of off-river storages), purchase projects, and interaction with floodplain take and greater assessment of connectivity issues through groundwater use and return flows issues to determine long-term impacts on declining Darling River flows.	Academy of Science	56

Recommendation	Source	Page
• Adjust sustainable diversion limits for the Northern Basin, with regards to a future hotter climate change and other effects on Darling River flows, informed by improved modelling and observed data analysis.		
Recommendation 8: Commission within 12 months an independent scientific panel to review progress in implementing the Academy of Science recommendations.	Academy of Science	57
Recommendation 1: NSW should modify water access arrangements under the Barwon–Darling Water Sharing Plan to protect low flows.	Vertessy	72
Recommendation 2: In preparing future Water Resource Plans for catchments in the northern Basin, QLD and NSW should ensure that they give greater attention to the need to maintain hydrologic connectivity in the Barwon–Darling River.	Vertessy	73
Recommendation 3: Basin governments should review and consider changes to the Menindee Lakes' operating procedures to provide greater drought resilience in the lower Darling region, encompassing the Menindee Lakes, the lower Darling River and the Anabranch.	Vertessy	73
Recommendation 4: NSW and the Australian government should re-evaluate the Menindee Lakes Water Saving Project to place a greater emphasis on improving water security and environmental outcomes in the lower Darling. Should the revised project contribute less to the agreed Sustainable Diversion Limits, the NSW government would need to commit to addressing the shortfall.	Vertessy	74
Recommendation 5: NSW and the Australian government should urgently finalise arrangements to support structural adjustment of lower Darling farm enterprises with permanent/perennial crops that depend on high reliability water entitlements, including appropriately targeted strategic water acquisition and compensation for the reconfiguration of farm businesses.	Vertessy	74
Recommendation 6: NSW and QLD should adopt an active event-based management approach to providing flows through the Barwon–Darling system. Flow management strategies should be implemented as soon as possible to protect first flushes, protect low flows, shepherd environmental releases, enhance system connectivity, and improve water quality.	Vertessy	75
Recommendation 8: NSW, QLD and the MDBA should publish their joint plans for implementation of the northern Basin Toolkit Measures and set an aggressive timeline for delivery. Immediate priority should be given to those measures that support native fish population recovery and connectivity.	Vertessy	76
Recommendation 14: NSW should review and refine the flow requirements to control stratification in weir pools deemed to be at high risk of fish deaths.	Vertessy	79
Recommendation 15: NSW and QLD should establish an agreed protocol to protect first flushes.	Vertessy	79
Recommendation 17: The Commonwealth Environmental Water Holder, the MDBA, the Victorian Environmental Water Holder and the NSW Department of Environmental and Heritage should cooperatively undertake a risk assessment to determine how best to manage environmental water during prolonged dry spells, taking into account uncertainty in future inflows.	Vertessy	80
Recommendation 18: The MDBA's recently announced Climate Change Research Program should be adequately resourced and supported by relevant specialist science	Vertessy	80

Recommendation	Source	Page
agencies and universities. A much better understanding of how climate change threatens Basin water availability and aquatic ecosystems must be obtained ahead of the 2026 Basin Plan review.		
Recommendation 25: Basin States should upgrade their Strategic Water Information Monitoring Plans to reflect the enhanced hydrologic monitoring requirements associated with the Basin Plan and the recently agreed Murray–Darling Basin Compliance Compact, and agree to commit the necessary resources to enable these plans to be fully implemented.	Vertessy	82

Appendix 4

Site visits

The review team made four site visits to Menindee and Wilcannia over the course of the Review, as set out below:

Visit one:

Date	Location	Action
31 May 2023	Civic Hall, Menindee	Community Listening
1 June 2023	Civic Hall, Menindee Menindee Lakes System Sunset Strip	Community Listening WaterNSW Infrastructure Tour Sites of local significance

Visit two:

Date	Location	Action
26 June 2023	Civic Hall, Menindee	Community Listening
27 June 2023	Civic Hall, Menindee	Community Listening
27 June 2023	Civic Hall, Menindee Shamrock Hill Vineyard	Community Listening Site Visit
28 June	Civic Hall, Menindee Lake Wetherell	Community Listening Aboriginal places of significance

Visit three:

Date	Location	Action
22 August 2023	Menindee	Stakeholder Consultation
23 August 2023	Wilcannia Broken Hill	Aboriginal Consultations: Wilcannia LALC, Wilcannia Barkandji Rangers Aboriginal Affairs
24 August 2023	Broken Hill	National Parks and Wildlife Service consultation Aboriginal Consultations – PBC Native Title, Barkandji Rangers

Visit four:

Date	Location	Action
4 September 2023	Broken Hill	Presentation of Executive Summary to Aboriginal Affairs NSW
5 September 2023	Menindee	Presentation of Executive Summary to community and Barkandji Rangers from Menindee and Wilcannia

Stakeholder meetings

The Review met with representatives from the following organisations or groups.

Aboriginal Affairs
Central Darling Shire Council
Commonwealth Environmental Water Holder
CSIRO
Department of Planning and Environment, Biodiversity, Conservation and Science
Department of Planning and Environment Water
Department of Water and Environmental Regulation (Western Australia)
Department of Primary Industries Fisheries
Far West Local Health District
Menindee Health Service (NSW Health)
Murray Darling Basin Authority
NSW Environment Protection Authority
NSW Ministerial Taskforce on Fish Passage (Chair)
NSW Police
Premier’s Department (Capability Development)
Sydney Water
Water NSW

Appendix 5

As part of the review process, OCSE invited submissions from agencies, stakeholders and community members of relevance to the Terms of Reference.

Submissions to the Review

The Review received 29 written submissions, of which two were marked confidential. The remaining 27 have been published with the report on the Office of Chief Scientist & Engineer website.

OCSE thanks the individuals, groups, organisations and agencies who took the time to prepare a submission. The information contained within was vital to shaping the report and framing its recommendations.

Public submissions were received from:

- Professor Darren Baldwin
- Barwon-Darling Water Inc
- Central Darling Shire Council
- Commonwealth Environmental Water Holder
- Confidential
- Confidential
- Darren Clifton
- CropLife Australia
- Department of Primary Industries (Fisheries)
- DPE Water
- Future Fisheries Veterinary Service Pty Ltd
- Adjunct Professor John Koehn
- Geoff Looney
- Rob Looney
- Rob McBride
- Murray–Darling Basin Authority (MDBA)
- Nature Conservation Council (NCC)
- New South Wales Aboriginal Land Council (NSWALC)
- NSW Irrigators' Council (NSWIC)
- NSW Reconstruction Authority
- NSW South-West Water Users Association (SWWU)
- The Pastoralists' Association of West Darling (PAWD)
- Malcolm Rouse
- Dr Stuart Rowland
- Water NSW
- Water Watch Radio
- Barbara Webster
- West Darling Fishing Club
- Professor John Williams

Appendix 6

Sentinel-2 algae mapping using the WaterNSW-Custom Algae Script in the Mid-Lower Darling

The following information was provided to the Review by DPE Water on behalf of WaterNSW. The Table numbering has been changed to be consistent with the Review report numbering conventions.

All images are from the 19-3-23 sentinel-2 satellite with the NSW-Custom Algae Script except for the time-lapse on pages 6 and 8 (Figures 7 and 9), these have date ranges.

Note that the algae script key in Table 1 was developed and optimised for cyanobacteria concentrations with the risk level based on recreational alert values. The results still should provide a guide for total algae (cyanobacteria + algae), but the key will underestimate total algae concentrations as shown in table 2. Also, the imagery date is more recent than sampling dates.

The cyanobacteria biovolumes are generally not that high. However importantly, the total algae biovolume (cyanobacteria + algae) are very high in the system in the areas around Menindee including upstream to Wilcannia, Louth and up to Brewarrina (Table 2). With the Darling system at most sites upstream having over 1,000ML/day, it is likely that this algae will flow down the system as a slug of algae.

Interestingly the fish kill in figure 9 (time-lapse) appears to coincide with an increase of algae in the area of the river.

The key to the approximate total algae (blue green and non-blue green) concentrations using the Custom Algae Script can be found Table 1. The actual values can potentially vary by a significant margin due to the geology of the waterbody, species of algae, turbidity, aquatic plants, time of day of the image capture, aerosols in the atmosphere, etc. This variability is a result of the nature of satellite imagery being a large-scale remote sensing format and is not function of the technology or the script itself. For this reason, these colours and descriptors are not the official **"Algae Alert Level"** but rather provide information on the **potential risk of algae.F**

Table A6.1: Observed risk levels based on the estimated photosynthetic activity for Custom Algae Script optimised for cyanobacteria.

Map Colour	**Risk Level –** Photosynthetic activity based on Chlorophyll-a	Starting concentration guide range	RACC recreational alert values approx. equivalence
Blue	Very low	<0.05 mm3/L	No Alert
Green	Low	0.05 to 0.5 mm3/L	Green
Yellow	Medium	0.5 to 5.0 mm3/L	Amber
Red	High	5.0 to 20.0 mm3/L	Red
Dark red	Extreme	> 20 mm3/L	Red

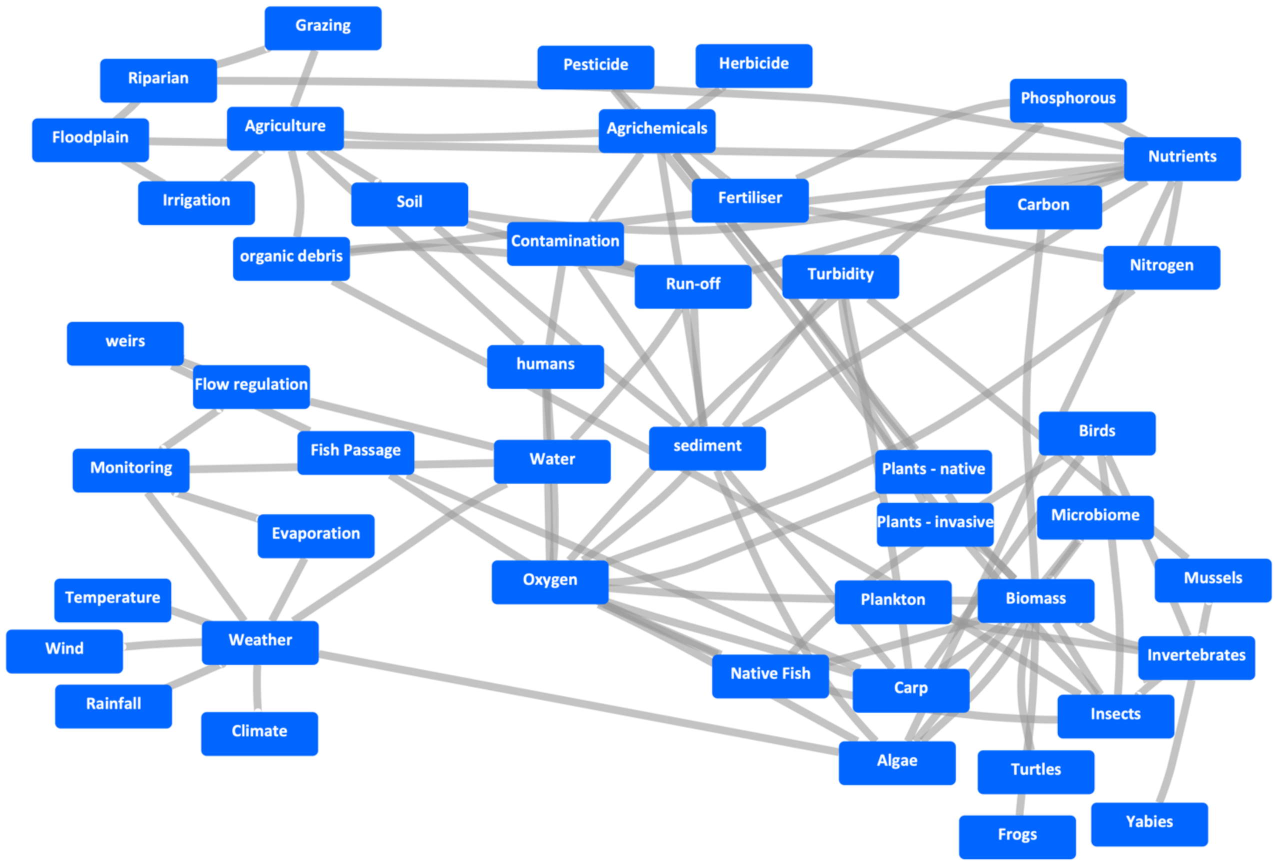
Table A6.2: Algae concentrations – highlighted are concentrations of concern.

Station Name	Date	Total algal biovolume (mm3/L)	Toxic Cyanobacterial biovolume (mm3/L)	Cyanobacterial biovolume (mm3/L)	RACC Region
422001 - Barwon River at Dangar Bridge (Walgett)	06-Mar-23	4.23	0.00	0.10	Far West
422002 - Barwon River at Brewarrina	06-Mar-23	28.52	0.00	0.08	Far West
Darling River at North Bourke Bridge (Boat Ramp)	21-Feb-23	5.58	0.08	0.75	Far West
425004 - Darling River at Louth	22-Feb-23	19.98	0.00	0.08	Far West
425008 - Darling River at Wilcannia	21-Feb-23	51.50	1.35	2.44	Far West
425012 - Darling River at Menindee Weir 32	22-Feb-23	10.51	1.19	1.87	Sunraysia
42510001 - Menindee Lakes at Lake Wetherell Site 1	20-Feb-23	9.20	0.35	2.81	Sunraysia
42510002 - Menindee Lakes at Lake Wetherell Site 2	20-Feb-23	26.17	1.99	8.17	Sunraysia
Menindee Lake at Lake Wetherell Station 3	20-Feb-23	26.08	0.50	4.41	Sunraysia
42510004 - Menindee Lakes at Lake Wetherell Site 4	21-Feb-23	27.71	1.87	5.94	Sunraysia
42510008 - Menindee Lakes at Tandure Lake Site 8	21-Feb-23	23.00	1.99	4.90	Sunraysia
42510009 Pamamaroo Inlet (Site 9)	20-Feb-23	23.73	3.58	5.21	Sunraysia
42510010 Pamamaroo Outlet / Regulator (Site 10)	20-Feb-23	19.57	0.38	1.85	Sunraysia
42510037 - Menindee Lakes at Copi Hollow	21-Feb-23	9.23	0.06	0.75	Sunraysia
Darling River BHWB Pumping Station @ Menindee	22-Feb-23	17.45	0.13	1.19	Sunraysia
42510034 - Menindee Lakes - Cawndilla Outlet	21-Feb-23	2.11	0.00	0.34	Sunraysia
42510013 Centre Pamamaroo (Site 13)	21-Feb-23	9.59	0.28	0.51	Sunraysia
Silver City Hwy	06-Mar-23	109.50	6.80	34.48	Sunraysia

Appendix 7

Conceptual network map of ecosystem and influencing factors

Showing interactions between key components of the Darling-Baaka ecosystem and factors driving ecosystem decline and fish deaths. Note this is a highly simplified representation used to inform conceptual thinking about these factors.



Appendix 8

Sediment and water analysis

Charles Sturt University

Menindee Lakes and Darling River Preliminary Water and Sediment Quality Assessment 2023

Corrigendum Revision (December 2023)

Report produced for the Office of the Chief Scientist and Engineer

Katie Doyle, An V. Vu, Zac Rolfe, Lee J. Baumgartner

To be cited as:

Doyle K., Vu A.V., Rolfe Z, Baumgartner L.J. (2023). Menindee Lakes and Darling River Preliminary Water and Sediment Quality Assessment 2023. Gulbali Institute, Albury NSW Australia.

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CORRIGENDUM

This version of the report corrects a rounding error. Table 10 did not contain SI units in the original version which led to a discrepancy when compared against SI units referenced in ANZECC guidelines. This has now been corrected and all references to this data have been updated accordingly. The report is unaltered in all other respects.

Executive Summary

Introduction

In March 2023, a mass fish death event occurred in the Darling River at Menindee, NSW. This event was similar to a 2019 incident where a million fish died due to low dissolved oxygen (DO) levels. While both events had low DO as a likely cause, the mechanisms differed; in 2019, severe drought and stagnant water led to algal blooms, whereas in 2023, extensive flooding initially benefited fish but left organic material and sediment, deteriorating water quality, and reducing DO levels. Fish mortality events are likely to occur again in future.

In response to community concerns for a baseline understanding of the health of the river, the Office of the Chief Scientist and Engineer (NSW) sought a report to summarise a rapid assessment of the Menindee Lakes / Darling River system to:

(1) establish a baseline understanding of water and sediment chemistry information and;

(2) aid in the development of any water / sediment quality management plans for future monitoring programs.

Methodology

This report details a sampling strategy for assessing water- and sediment quality in the Menindee Lakes / Darling River (Menindee). Sampling involved a combination of in-situ measurements (edge- and middle- sampling using a two water quality meters (Horiba, Sonde)) and water and sediment samples for laboratory analysis (including nutrients in water, BOD, COD, metals, herbicides and pesticides). These results were then compared to available ANZECC guideline trigger values for water and sediment quality in slightly – moderately disturbed systems. This sampling plan (methodology) and the results presented here are a snapshot from August 2023 and can be used as baseline data and applied for future applications.

Results and Conclusion

Nutrients in water: Nutrient levels (e.g. phosphorus, nitrogen) generally in exceeded ANZECC water quality guidelines for slightly-moderately disturbed ecosystems. In addition, chlorophyll and dissolved oxygen results indicated an algal bloom was already present in the Darling River / Menindee Lakes system and nutrient levels were elevated. At the present levels, it is predicted that any change in temperature and / or water flow (e.g. drought conditions), or the further addition of nutrients into the waterway may see increased algal blooms and low dissolved oxygen levels and should be monitored for potential fish death events in the near future.

Metals in water and sediment: Aluminium and copper were detected at all sites (S1-6) in the water column and exceeded ANZECC guideline trigger values. In the sediment samples, aluminium, barium, cobalt, chromium, copper, iron, lanthanum, manganese, nickel, lead, strontium, titanium, vanadium, zinc were detected.

Pesticides / Herbicides in water and sediment: Several herbicides including metolachlor, atrazine, simazine, terbuthylazine, tebuthiuron, clopyralid, fluroxpyr were detected from the laboratory-analysed water samples. Pesticides / herbicides were not detected in sediment samples.

The results presented here (in particular, the detection of moderate nutrient levels and herbicides) are consistent with agricultural land-use in the area. The detection of an algal bloom during the August sampling event requires further monitoring prior to temperatures increasing (e.g. summer) and flows declining (e.g. during drought conditions). Water and sediment quality should be monitored in future to detect longer-term trends. Water and sediment quality results can be used as a baseline to compare to other future sampling events and to aid in the development of any water / sediment quality management plans for future monitoring and fish death prevention programs.

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1. Introduction

During March 2023, a mass fish death event occurred in the Darling River at Menindee, far west New South Wales (NSW) (Figure 1). A similar event took place in 2019, during which the devastating drought in New South Wales led to the demise of up to one million fish in the same area (Figure 1). The fish deaths likely occurred because of low dissolved oxygen (DO) levels, but the underlying mechanisms leading to these low DO levels are believed to be different. The occurrence of low DO levels, leading to the fish mortality, arises from a combination of various factors. These can include prevailing weather conditions, blue-green algae outbreaks, the volume of water present in the river before and during the event and the overall quality of the water (Edwards and Joehnk, 2019; CSIRO, 2023).

In the case of 2019, the low DO was primarily attributed to severe drought and low river flows. These conditions gave rise to stagnant water and stratification (layering) within the river, fostering the development of an extensive blue-green algae bloom. Subsequently, the abrupt arrival of a cold front weather system caused a sudden mixing of deoxygenated bottom waters (anoxic) with the rest of the water column, resulting in a decline in DO levels (CSIRO, 2023).

For the 2023 event, extensive flooding in Menindee and the areas upstream between 2022–2023 had a significant positive impact on fish populations. This flooding created suitable conditions for fish spawning and the growth of young fish. However, as the floodwaters receded, a substantial accumulation of organic material and sediment persisted in the water. This deterioration in water quality resulted in lower levels of dissolved oxygen. Furthermore, as water levels dropped, fish became concentrated in the main river channel, intensifying their competition for the limited oxygen available. This, in turn, contributed to the fish deaths.

Fish deaths in Jan 2019
Photo credit: Amy Edwards and Klaus Joehnk

Fish deaths in Mar 2023
Photo credit: Graeme McCrabb

Figure 1. Dead fish in the Darling River at Menindee

Fish mortality events are likely to occur again in future. Therefore, it is important to establish a baseline understanding of water and sediment quality information and develop a sound sampling methodology for future applications.

In response to community concerns for a baseline understanding of the health of the river, this report summarises a rapid assessment of the Menindee Lakes / Darling River system based on a number of water and sediment quality parameters to 1) aid in the detection of deteriorating water conditions or pollution and 2) aid in the development of any water / sediment quality management plans for future monitoring programs.

2. Sampling Methodology

2.1 Sampling sites

Sampling was undertaken at six sites (S1–S6) between 8–9 August 2023 (Table 1, Figure 2). At each site, both the edge of the river/lake and middle of river/lake were sampled (Figure 3).

Table 1. Name and location of each sampling site

Site name	Site samples	GPS co-ordinates	
Weir 32	S1 (Middle)	142.375833°E	-32.400533°S
	S1 (Edge)	142.375767° E	-32.400600° S
Menindee Lake	S2 (Middle)	142.367100° E	-32.393450° S
	S2 (Edge)	142.370488° E	-32.398097° S
Old Town Weir	S3 (Middle)	142.431617° E	-32.389750° S
	S3 (Edge)	142.431400° E	-32.389833° S
Lake Pamamaroo	S4 (Middle)	142.497983° E	-32.301467° S
	S4 (Edge)	142.500083° E	-32.302350° S
Pamamaroo/Weatherall outlets	S5 (Middle)	142.499700° E	-32.305467° S
	S5 (Edge)	142.499787° E	-32.305561° S
Lake Weatherall	S6 (Middle)	142.513567° E	-32.308200° S
	S6 (Edge)	142.511712° E	-32.312434° S

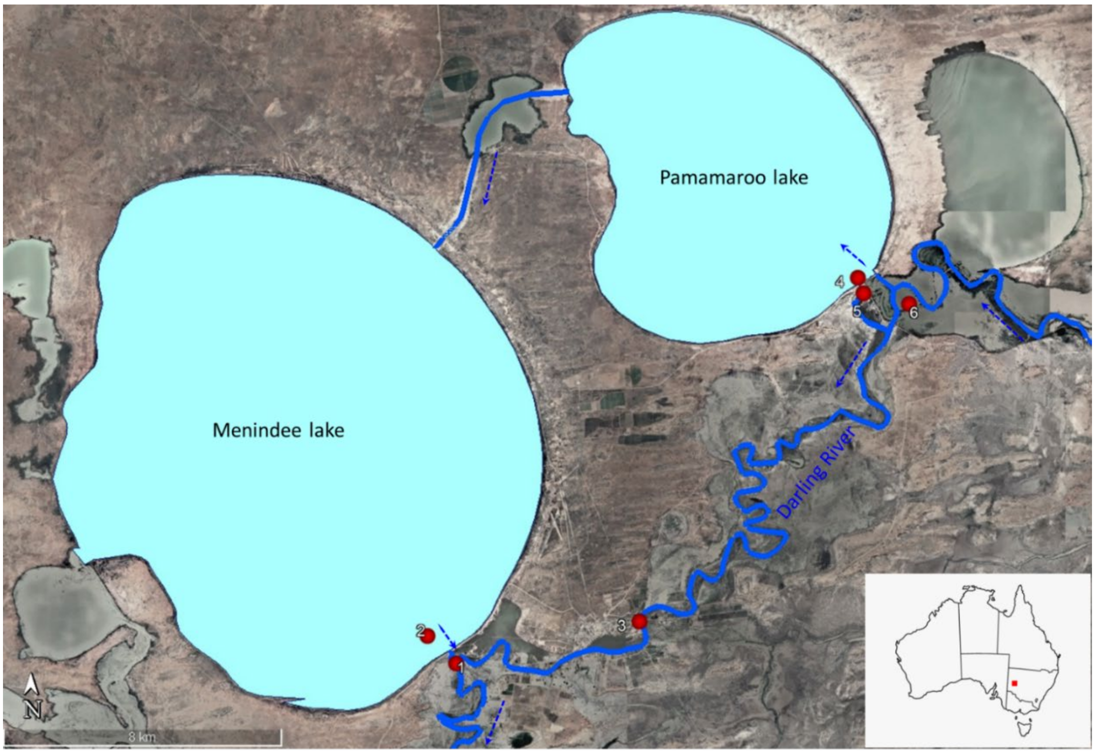


Figure 2. Samling sites (1–6) at Menindee, NSW. Arrows indicate water flow direction.

Sampling consisted of 1) in-situ water quality measurements using water quality meters (Sonde / Horiba) and 2) water- and sediment samples that were collected and sent for laboratory analysis (https://www.alsglobal.com/en/, Victoria)(Figure 3).

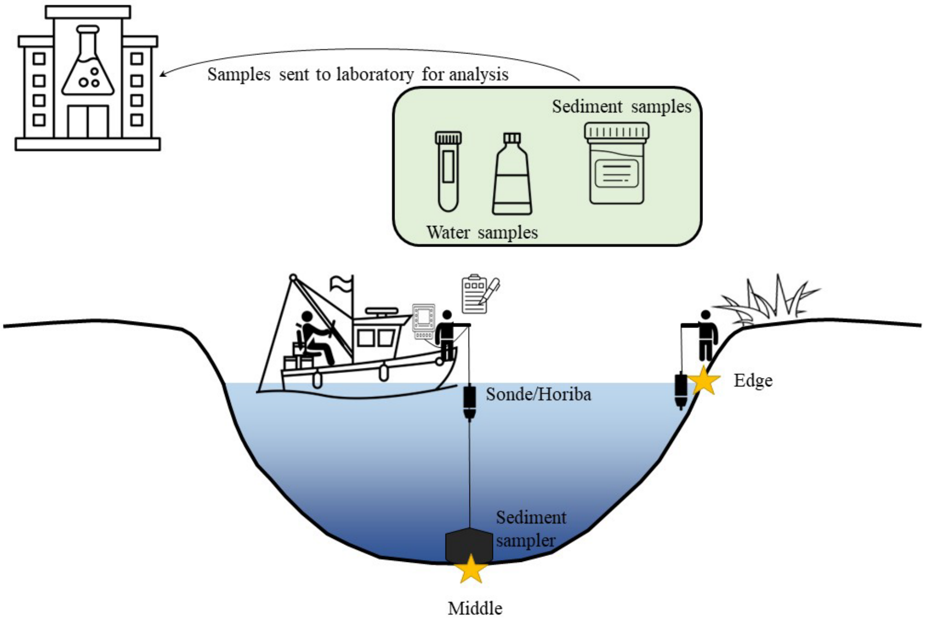


Figure 3. Schematic of middle and edge-sampling methodology including in-situ measurements (Sonde / Horiba) and water and sediment samples collected for laboratory analysis.

At Site's 1, 3 and 5, additional in-situ measurements were taken at intervals downstream of the sampling site as well as throughout the water column to understand water quality parameters across a vertical and horizontal profile in the Darling River (Figure 4).

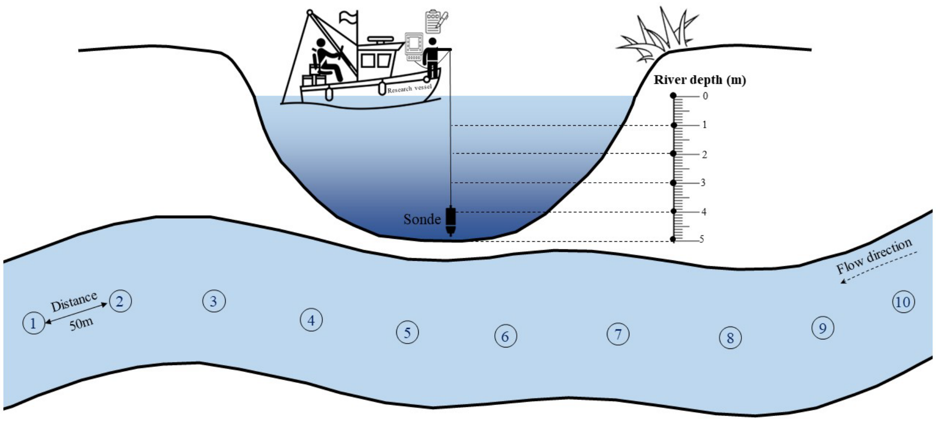


Figure 4. Schematic of additional in-situ sampling methodology (using the Sonde meter) at Site's 1, 3 and 5 (Darling River sites).

2.2 Water and sediment quality parameters

The following water and sediment parameters were collected:

In-situ measurements

1. Portable Horiba water quality meter (Model U-5000, Made in Japan, 2021). Parameters include;
   - Turbidity (NTU)

2. Portable Sonde meter (EX-02 Multiparameter). Parameters include;
   - Temperature (°C)
   - pH
   - Specific conductivity (µS/cm)
   - Salinity (g/L)
   - Dissolved oxygen (mg/L)
   - Dissolved oxygen saturation (%)
   - Chlorophyll (µg/L)
   - Chlorophyll (RFU)
   - Phycocyanin or PC (RFU)
   - Phycocyanin or PC (µg/L)

Water samples (laboratory analysis)

- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Nutrients (TN, P, Ammonia, Nitrate, Nitrate, NOx)
- Metals
- Herbicides
- Pesticides

Sediment samples (laboratory analysis)

- Metals
- Herbicides
- Pesticides

2.3 Comparison of water and sediment quality results to the ANZECC guidelines

Once the water and sediment results were received from the field sampling (in-situ measurements) or following laboratory analysis, water and sediment results were then compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000). These guidelines can be sourced at:

https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf

Interpreting the guidelines: The ANZECC guidelines include numerical concentration limits recommended to support and maintain a designated water use. The ANZECC guidelines (*'guideline trigger values'*) are used as a general tool for assessing water / sediment quality and are the key to determining water quality objectives that protect and support the designated environmental values of our water resources, and against which performance can be measured (ANZECC 2000).

'Guideline trigger values' are concentrations that, if exceeded, would indicate a *potential* environmental problem, and so 'trigger' a management response, e.g. further investigation and/or subsequent refinement of the guidelines according to local conditions (ANZECC 2000). For the present report, the level of protection applied was 95% (slightly to moderately disturbed ecosystems, Appendix 1)(ANZECC 2000), though 80%, 90% and 99% protection values are presented for reference. (For further information on protection levels, see page 3.4-3 of ANZECC 2000).

Water quality parameters can be divided into those that have direct toxic effects on organisms and animals (e.g. insecticides, herbicides, heavy metals and temperature) and those that indirectly affect ecosystems causing a problem for a specified environmental value (e.g. nutrients, turbidity and enrichment with organic matter). Where guideline values were not available, the data presented here is considered as a rapid baseline assessment tool for understanding and monitoring trends in water / sediment quality for future applications (ANZECC 2000).

3. Results

3.1. Site images (Figure 5)

Site 1: Weir 32

Water from the Menindee lake flowing into the Darling River

Mixing water in the Darling River

Site 2: Menindee lake

605 metres from the lake bank

Menindee lake bank

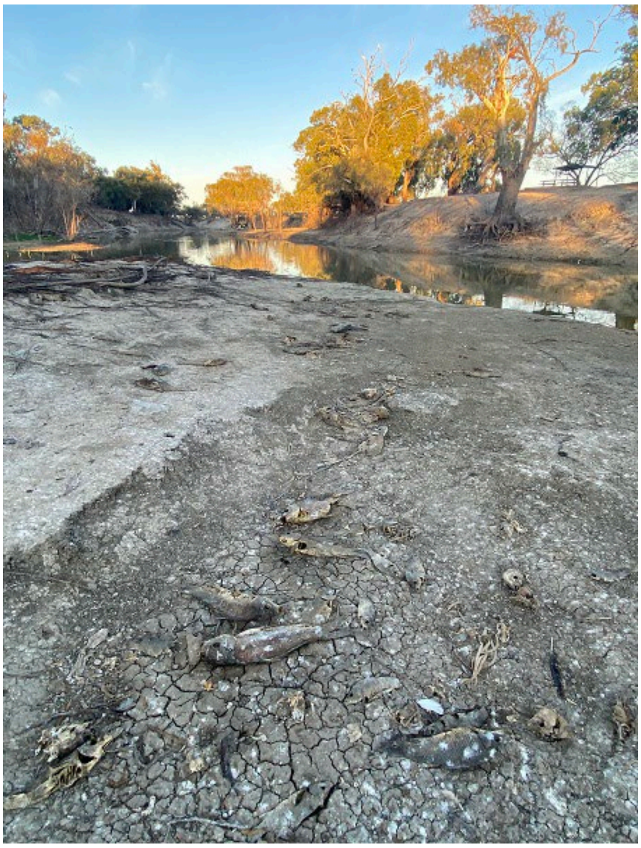
Site 3: Old Town Weir, Darling River

Site 4: Pamamaroo lake

175 metres away from the lake bank

Pamamaroo lake bank

Site 5: Pamamaroo / Weatherall Outlets



Site 6: the Darling River (flooded wetland)

720 metres away from the bank

River bank

3.2. Results: Physio-chemical water quality (in-situ measurements, raw data)

Table 2. In-situ water quality results measured at Sites 1–6 at Menindee, NSW (measured by Sonde water quality meter. NTU was measured by Horiba water quality meter).

Site	Temperature (ºC)	Dissolved oxygen (mg/L)	Dissolved gas saturation (%)	Conductivity (µS/cm)	Specific Conductivity (µS/cm)	pH	Chlorophyll (µg/L)	Chlorophyll (RFU)	Phycocyanin or PC (RFU)	Phycocyanin or PC (µg/L)	Turbidity (NTU)
S1 (Middle)	12.298	7.5	70.2	639	844	8.17	36.85	6.65	0.38	0.98	95.2
S1 (Edge)	12.386	8.28	77.7	605	797	8.22	33.89	5.91	0.42	1.01	81.3
S2 (Middle)	11.794	10.70	99.0	368	492.7	8.61	7.42	-0.71*	-0.41*	0.19	90.5
S2 (Edge)	12.848	11.15	105.6	376	490.2	8.73	7.19	-0.77*	0.37	0.97	97.3
S3 (Middle)	12.667	8.13	76.7	618	808	8.22	35.35	6.27	0.62	1.22	60.2
S3 (Edge)	14.405	10.4	102	643	807	8.43	26.47	4.05	0.48	1.08	87.2
S4 (Middle)	13.474	10.57	101.6	613	786	8.56	41.07	7.70	0.65	1.25	72.2
S4 (Edge)	16.391	11.66	119.4	644	770	8.63	16.77	1.63	0	0.60	84.5
S5 (Middle)	12.943	9.54	90.7	606	787	8.34	26.96	4.17	0.46	1.05	83.1
S5 (Edge)	13.301	9.87	94.6	604	777	8.40	21.28	2.75	0.27	0.87	93.5
S6 (Middle)	12.596	12.01	113.2	655	859	8.72	31.84	5.39	0.52	1.12	46.7
S6 (Edge)	13.808	11.08	107.3	684	870	8.60	31.28	5.25	0.73	1.33	86.5

*Negative values unreliable indicators as they are likely a result of high NTU (turbidity) levels and potential clogging of wipers.

Various water quality parameters were also measured at different depths in the water column along selected transects at Site 1, Site 3 and Site 5, Darling River.

Site 1 (Weir 32, Darling River)

Table 3. In-situ water quality parameters measured (Sonde meter) along a section of 52 m in the Darling River, including water temperature (°C), dissolved oxygen (mg/L), pH *Error! Reference source not found.* ***and chlorophyll (µg/L).***

	Water temperature (°C)		***Dissolved Oxygen (mg/L)***		***pH***		***Chlorophyll (µg/L)***	
	Distance (m)		***Distance (m)***		***Distance (m)***		***Distance (m)***	
Depth (m)	0	52	0	52	0	52	0	52
1	12.298	12.744	7.50	11.03	8.16	8.44	36.85	53.61
2	12.159	12.100	7.70	8.48	8.15	8.20	37.68	62.29
3	12.073	12.029	7.62	7.66	8.13	8.11	53.70	52.90

Site 3 (Old Town Weir, Darling River)

Table 4. In-situ water quality parameters measured by Sonde meter at different depths along a section of 461 m in the Darling River (Site 3): water temperature (°C), dissolved oxygen (mg/L), pH and chlorophyll (µg/L). Dashed lines represent no record due to shallow water.

Depth (m)	***Water temperature (°C)***									
	Distance travelled									
	0	**51**	**105**	**159**	**210**	**260**	**312**	**362**	**413**	**461**
1	12.976	12.627	13.107	12.667	12.614	12.971	12.521	12.542	12.474	12.453
2	12.642	12.566	12.554	12.514	12.498	12.572	12.733	12.467	12.434	12.403
3	12.560	12.528	12.519	12.488	12.476	12.487	-	12.437	12.401	12.395
4	12.545	12.519	12.515	12.487	12.473	12.499	-	12.414	12.404	12.382
5	12.556	12.529	12.511	12.487	-	-	-	12.420	12.418	12.397
Depth (m)	***Dissolved Oxygen (mg/L)***									
	0	**51**	**105**	**159**	**210**	**260**	**312**	**362**	**413**	**461**
1	8.70	7.86	9.22	8.13	8.03	9.42	8.35	8.39	8.07	8.25
2	8.45	7.83	8.05	7.76	7.84	8.38	8.53	7.93	7.90	7.87
3	7.83	7.59	7.42	7.71	7.73	7.85	-	7.79	7.65	7.78
4	5.57	7.36	7.23	7.63	7.56	7.56	-	7.64	7.50	7.68
5	7.12	7.19	6.99	7.58	-	-	-	7.39	7.29	7.50
Depth (m)	***pH***									
	0	**51**	**105**	**159**	**210**	**260**	**312**	**362**	**413**	**461**
1	8.30	8.18	8.31	8.22	8.18	8.32	8.19	8.21	8.19	8.19
2	8.19	8.17	8.15	8.18	8.16	8.20	8.25	8.17	8.17	8.17
3	8.15	8.14	8.13	8.17	8.16	8.16	-	8.16	8.15	8.17
4	8.14	8.12	8.11	8.16	8.14	8.12	-	8.15	8.14	8.16
5	8.09	8.10	8.09	8.16	-	-	-	8.13	8.12	8.14
Depth (m)	***Chlorophyll (µg/L)***									
	0	**51**	**105**	**159**	**210**	**260**	**312**	**362**	**413**	**461**
1	45.37	36.15	29.21	35.35	28.09	35.06	35.11	33.20	28.11	29.51
2	36.26	35.58	32.25	36.16	27.92	35.75	46.15	33.88	29.09	28.76
3	37.35	28.52	30.05	38.13	26.09	29.88	-	27.39	28.79	28.85
4	35.65	36.52	37.81	36.04	27.59	44.29	-	29.76	28.91	32.76
5	33.32	42.86	29.08	33.29	-	-	-	31.52	31.96	41.30

Site 5 (Pamamaroo / Weatherall outlets)

Table 5. Water quality parameters measured by Sonde meter at different depths along a section of 470 m in the Darling River (Site 3): water temperature (°C), dissolved oxygen (mg/L), pH and chlorophyll (µg/L). Dashed lines represent no record due to shallow water.

Depth (m)	***Temperature (°C)***									
	Distance travelled (m)									
	0	53	111	164	217	267	317	366	419	470
1	12.931	12.938	12.939	12.919	12.905	12.895	12.847	12.811	12.831	12.767
1.5 to 2	12.958	12.926	12.925	-	12.906	12.863	-	-	12.840	-
	Dissolved oxygen (mg/L)									
	0	53	111	164	217	267	317	366	419	470
1	9.50	9.44	9.48	9.49	9.49	9.56	9.46	9.46	9.52	9.47
1.5 to 2	9.50	9.38	9.42	-	9.42	9.47	-	-	9.40	-
	pH									
	0	53	111	164	217	267	317	366	419	470
1	8.34	8.33	8.31	8.32	8.32	8.32	8.31	8.32	8.32	8.31
1.5 to 2	8.34	8.31	8.30	-	8.31	8.31	-	-	8.31	-
	Chlorophyll (µg/L)									
	0	53	111	164	217	267	317	366	419	470
1	29.96	31.16	27.53	30.70	33.02	26.82	30.92	29.56	29.93	36.62
1.5 to 2	28.23	36.00	29.38	-	33.36	37.01	-	-	35.84	-

3.3. Results: Physio-chemical water quality (raw data, laboratory analysis)

Table 6. BOD, COD and nutrients in water chemistry results (mg/L). NS: no sample taken as this could not be analysed within the 24 hr time period.

	BOD / BOD5	COD / COD	TKN	TOTAL P	TN	Ammonia ($NH3^+$)	Nitrite (NO2)	Nitrate (NO3)	NOX
S1 (Middle)	4	31	1.2	0.22	1.2	< 0.1	< 0.01	0.01	0.01
S1 (Edge)	3	27	1.2	0.35	1.2	0.2	< 0.01	0.02	0.02
S2 (Middle)	*NS*	27	1	0.31	1	< 0.1	< 0.01	0.01	0.01
S2 (Edge)	*NS*	24	1.1	0.34	1.1	< 0.1	< 0.01	< 0.01	< 0.01
S3 (Middle)	6	37	1.4	0.14	1.4	< 0.1	< 0.01	< 0.01	< 0.01
S3 (Edge)	5	33	1.3	0.13	1.3	< 0.1	< 0.01	< 0.01	< 0.01
S4 (Middle)	*NS*	35	1.3	0.12	1.3	< 0.1	< 0.01	0.02	0.02
S4 (Edge)	*NS*	33	1.1	0.16	1.1	< 0.1	< 0.01	0.01	0.01
S5 (Middle)	4	34	1.1	0.18	1.1	< 0.1	< 0.01	< 0.01	< 0.01
S5 (Edge)	4	32	1.4	0.13	1.4	< 0.1	< 0.01	< 0.01	< 0.01
S6 (Middle)	*NS*	33	1.3	0.1	1.3	< 0.1	< 0.01	0.01	0.01
S6 (Edge)	*NS*	35	1.2	0.1	1.2	< 0.1	< 0.01	< 0.01	< 0.01

3.4. Results: Physio-chemical water quality results and comparisons with ANZECC guidelines

Table 7. Physio-chemical water quality results including chlorophyll, P, N, NOx, DO, pH, ammonia and nitrate and comparisons of results with ANZECC guidelines.

Site	Chlorophyll (µg/L)	Total P	TN	NOX	DO (%)	pH	Ammonia ($NH3^+$)	Nitrate (NO3)
S1 (Middle)	36.85	0.22	1.2	0.01	70.2	8.17	< 0.1	0.01
S1 (Edge)	33.89	0.35	1.2	0.02	77.7	8.22	0.2	0.02
S2 (Middle)	7.42	0.31	1	0.01	99.0	8.61	< 0.1	0.01
S2 (Edge)	7.19	0.34	1.1	< 0.01	105.6	8.73	< 0.1	< 0.01
S3 (Middle)	35.35	0.14	1.4	< 0.01	76.7	8.22	< 0.1	< 0.01
S3 (Edge)	26.47	0.13	1.3	< 0.01	102	8.43	< 0.1	< 0.01
S4 (Middle)	41.07	0.12	1.3	0.02	101.6	8.56	< 0.1	0.02
S4 (Edge)	16.77	0.16	1.1	0.01	119.4	8.63	< 0.1	0.01
S5 (Middle)	26.96	0.18	1.1	< 0.01	90.7	8.34	< 0.1	< 0.01
S5 (Edge)	21.28	0.13	1.4	< 0.01	94.6	8.40	< 0.1	< 0.01
S6 (Middle)	31.84	0.1	1.3	0.01	113.2	8.72	< 0.1	0.01
S6 (Edge)	31.28	0.1	1.2	< 0.01	107.3	8.60	< 0.1	< 0.01
Default ANZECC trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems								
Lowland river	*5*	*0.050*	*0.5*	*0.04*	*85-110*	*6.5-8.0*	*0.9 (95%)*	*0.7 (95%)*
Freshwater lakes / reservoirs	*5*	*0.010*	*0.35*	*0.01*	*90-110*	*6.5-8.0*	-	-

*Grey shading are those values that exceed the default trigger values for slightly disturbed ecosystems. See Appendix 2 for values. Dashed lines represent parameters that do not have trigger values.

Interpretation of physio-chemical water quality results

Various naturally occurring physical and chemical stressors can lead to significant deterioration of aquatic ecosystems when ambient values are too high and/or too low. Some of these physical and chemical stressors include nutrients (e.g. phosphorus, total nitrogen, NOx, nitrate, ammonia), dissolved oxygen, turbidity, temperature, salinity and pH (ANZECC 2000, Tables 2–6).

The raw data presented in Tables 2 – 6 provide a single snapshot of baseline information for physio-chemical parameters between August 8–9 2023.

- The Menindee Lakes sites and Darling River sites were all characterised by high turbidity values (Table 2).
- Nutrient levels (e.g. total phosphorus (TP), total nitrogen (TN)) were, in general, in excess of ANZECC water quality trigger values for slightly-moderately disturbed ecosystems (Table 6

and 7). Oxides of nitrogen (NOx) slightly exceeded trigger values for lowland rivers (Site 1, Weir 32) and freshwater lakes at Site 4 Pamamaroo Lake (Table 6 and 7).

- Chlorophyll exceeded ANZECC water quality trigger values for slightly-moderately disturbed ecosystems (Table 7) at all sites. However, in-situ analysis with the Sonde may not be as precise as certified extractive laboratory analysis, so its limitations should be considered, and combining it with traditional methods is advisable to improve accuracy, as it is meant to complement rather than replace them for chlorophyll determination. (Source: The Basics of Chlorophyll Measurement (ysi.com)). Nonetheless, observations of an algal bloom were apparent at Sites 1 and 3, coupled with the chlorophyll and phycocyanin results (Tables 2–6) indicate the presence of an algal bloom in the Darling River / Menindee Lakes system.
- pH range consistently exceeded ANZECC water quality trigger values for slightly-moderately disturbed ecosystems (Table 7).

Overall, the results summarised in Tables 2–6 indicate moderate nutrient loads in the system and are representative of agricultural land use in the area. At the present levels, it is predicted that any change in temperature (as summer approaches) and / or water flow (e.g. drought conditions), or the further addition of nutrients into the waterway may see increased algal blooms and low dissolved oxygen levels, and should be monitored for potential fish death events in the near future.

3.5. Results: Metals in water and sediment

Background: Some metals, such as manganese, iron, copper, and zinc are essential micronutrients. They are essential to life in the right concentrations, but in excess, these chemicals can be toxic. At the same time, chronic low exposures to heavy metals can have serious health effects in the long run (ANZECC 2000).

The recommended guideline values for a range of metals in freshwaters are listed in Table 3.4.1 of the Guidelines (Appendix 3) and for sediment metal contaminants are listed in Table 3.5.1 of the ANZECC guidelines (Appendix 4). In some cases, no DGVs will be specified for a toxicant of interest. This generally reflects absence of an adequate dataset for that toxicant. This is particularly notable with sediment guideline values, where only nine metal values contain a reference value (Appendix 4).

Raw data for metals in water and the associated ANZECC guidelines trigger values for freshwater is presented in Table 8. Raw data for metals in sediments and the associated ANZECC guidelines trigger values for sediment is presented in Table 9.

In water, both aluminium (Al) and copper (Cu) were detected at most sites above the ANZECC Guideline Trigger Values (Table 8). Barium, cobalt, chromium, iron, molybdenum, strontium, titanium and vanadium were also detected but no guideline values were specified (Table 6).

In sediment, no metals exceeded the available trigger values for sediments (Table 9). However, aluminium, barium, cobalt, iron, manganese, titanium, vanadium were all detected but, again, no guideline reference values are available (Table 9).

Water samples (laboratory analysis) results

Table 8. Metals in water (raw data) and associated ANZECC guidelines trigger values

Site	AG	AL	AS	B	BA	BE	CD	CO	CR	CU	FE	HG	MN	MO	NI	PB	SB	SE	SN	SR	TI	TL	V	ZN
S1E	< 0.001	1.6	0.003	0.07	0.13	< 0.001	< 0.0002	0.001	0.002	0.003	1.6	< 0.0001	0.084	0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.41	0.016	< 0.001	0.01	0.005
S1M	< 0.001	2.4	0.006	0.08	0.1	< 0.001	< 0.0002	< 0.001	0.003	0.004	2.3	< 0.0001	0.052	0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.31	0.02	< 0.001	0.015	0.006
S2E	< 0.001	2.2	0.006	0.08	0.099	< 0.001	< 0.0002	< 0.001	0.003	0.004	2.2	< 0.0001	0.037	0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.31	0.019	< 0.001	0.015	0.005
S2M	< 0.001	2.7	0.006	0.08	0.11	< 0.001	< 0.0002	< 0.001	0.004	0.005	2.6	< 0.0001	0.04	0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.32	0.023	< 0.001	0.017	0.007
S3E	< 0.001	0.98	0.003	0.08	0.14	< 0.001	< 0.0002	0.001	0.002	0.003	1	< 0.0001	0.097	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.47	0.009	< 0.001	0.007	0.003
S3M	< 0.001	0.87	0.002	0.08	0.14	< 0.001	< 0.0002	0.001	0.002	0.003	0.89	< 0.0001	0.091	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.46	0.008	< 0.001	0.007	0.003
S4E	< 0.001	1.2	0.003	0.08	0.14	< 0.001	< 0.0002	0.001	0.002	0.003	1.2	< 0.0001	0.092	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.48	0.012	< 0.001	0.007	0.003
S4M	< 0.001	1.2	0.003	0.08	0.13	< 0.001	< 0.0002	< 0.001	0.002	0.003	1.2	< 0.0001	0.065	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.44	0.011	< 0.001	0.008	0.004
S5E	< 0.001	1.5	0.003	0.08	0.13	< 0.001	< 0.0002	0.001	0.002	0.003	1.5	< 0.0001	0.097	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.46	0.014	< 0.001	0.007	0.004
S5M	< 0.001	1.5	0.003	0.08	0.13	< 0.001	< 0.0002	0.001	0.002	0.003	1.5	< 0.0001	0.1	0.002	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.46	0.014	< 0.001	0.007	0.004
S6E	< 0.001	0.97	0.002	0.07	0.14	< 0.001	< 0.0002	0.001	0.002	0.003	0.99	< 0.0001	0.11	0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.51	0.009	< 0.001	0.006	0.004
S6M	< 0.001	0.53	0.002	0.07	0.14	< 0.001	< 0.0002	< 0.001	0.001	0.002	0.43	< 0.0001	0.081	0.001	0.003	< 0.001	< 0.001	< 0.001	< 0.001	0.52	0.018	< 0.001	0.005	0.003
ANZECC Trigger Values (converted to mg/L)																								
99%	-	0.027	0.001	0.090	-	-	0.00006	-	-	0.001	-	0.00006	1.2	-	0.0088	0.001	-	0.055	-	-	-	-	-	0.0024
95%	-	0.055	0.024	0.370	-	-	0.0002	-	-	0.0014	-	0.0006	1.9	-	0.011	0.0034	-	0.011	-	-	-	-	-	0.008
90%	-	0.080	0.094	0.680	-	-	0.0004	-	-	0.0018	-	0.0019	2.5	-	0.013	0.0056	-	0.018	-	-	-	-	-	0.015
80%	-	0.15	0.36	1.3	-	-	0.0008	-	-	0.0025	-	0.0054	3.6	-	0.034	0.0094	-	0.034	-	-	-	-	-	0.031

*Green indicates no laboratory detection. Grey indicates sites / results that exceed 95% trigger values. (ANZECC Guidelines Trigger Values https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf) Appendix 3. Dashed lines represent parameters that do not have trigger values.

Sediment samples (laboratory analysis) results

Table 9. Metals in sediment (raw data) and associated ANZECC guidelines trigger values

Site	AG	AL	AS	B	BA	BE	CD	CO	CR	CU	FE	HG
S1E	< 5	17000	< 5	< 10	130	< 5	< 0.2	11	21	10	17000	< 0.05
S1M	< 5	12000	< 5	< 10	120	< 5	< 0.2	9	14	8	12000	< 0.05
S2E	< 5	6700	< 5	< 10	37	< 5	< 0.2	< 5	8	< 5	6200	< 0.05
S2M	< 5	20000	< 5	< 10	100	< 5	< 0.2	7	20	10	16000	< 0.05
S3E	< 5	12000	< 5	< 10	68	< 5	< 0.2	8	14	9	10000	< 0.05
S3M	< 5	22000	< 5	< 10	130	< 5	< 0.2	9	23	14	19000	< 0.05
S4E	< 5	1600	< 5	< 10	15	< 5	< 0.2	< 5	< 5	< 5	1800	< 0.05
S4M	< 5	18000	< 5	< 10	100	< 5	< 0.2	7	19	9	15000	< 0.05
S5E	< 5	6100	< 5	< 10	42	< 5	< 0.2	< 5	7	< 5	6100	< 0.05
S5M	< 5	19000	< 5	< 10	110	< 5	< 0.2	7	18	10	15000	< 0.05
S6E	< 5	20000	6	< 10	140	< 5	< 0.2	9	23	10	17000	< 0.05
S6M	< 5	24000	< 5	< 10	120	< 5	< 0.2	8	24	12	19000	< 0.05
ANZECC Default Guideline Values (converted to mg/kg)												
DGV	1.0	-	-	-	-	-	1.5	-	80	65	-	0.15
GV-high	4.0	-	-	-	-	-	10	-	370	270	-	1.0

Metals in sediment continued.

Site	LA	MN	MO	NI	PB	SB	SE	SN	SR	TH	TI	TL	U	V	ZN
S1E	15	360	< 5	14	7	< 5	< 3	< 5	150	< 5	89	< 5	< 5	28	28
S1M	13	590	< 5	11	11	< 5	< 3	< 5	42	< 5	26	< 5	< 5	22	22
S2E	9	110	< 5	5	< 5	< 5	< 3	< 5	13	< 5	23	< 5	< 5	12	12
S2M	18	230	< 5	13	8	< 5	< 3	< 5	29	6	52	< 5	< 5	34	29
S3E	11	130	< 5	11	7	< 5	< 3	< 5	29	< 5	53	< 5	< 5	37	23
S3M	17	540	< 5	16	11	< 5	< 3	< 5	44	< 5	51	< 5	< 5	43	39
S4E	< 5	32	< 5	< 5	< 5	< 5	< 3	< 5	< 5	< 5	20	< 5	< 5	6	< 5
S4M	16	280	< 5	13	7	< 5	< 3	< 5	33	< 5	55	< 5	< 5	29	29
S5E	7	180	< 5	5	< 5	< 5	< 3	< 5	21	< 5	46	< 5	< 5	13	12
S5M	13	360	< 5	12	8	< 5	< 3	< 5	48	< 5	73	< 5	< 5	36	28
S6E	16	540	< 5	15	7	< 5	< 3	< 5	53	< 5	80	< 5	< 5	51	30
S6M	17	340	< 5	16	8	< 5	< 3	< 5	35	< 5	63	< 5	< 5	38	36
DGV	-	-	-	21	50	-	-	-	-	-	-	-	-	-	200
GV-high	-	-	-	52	220	-	-	-	-	-	-	-	-	-	400

*Green indicates no laboratory detection. ANZECC Guidelines Trigger Values for sediments are provided in Appendix 4. Dashed lines represent parameters that do not have trigger values.

3.6. Results: Pesticides / Herbicides in water and sediment

Background: Pesticides represent a large and complex group of organic toxicants because they incorporate insecticides, acaricides, herbicides, algicides and fungicides. In addition, the behaviour (e.g. persistence, partitioning) and toxicity of pesticides varies greatly, making it difficult to generalise about risks. Pesticides generally enter water from sources in the primary industry sector, primarily agriculture (ANZECC 2000).

Pesticides / Herbicides in Water

Several herbicides including metolachlor, atrazine, simazine, terbuthylazine, tebuthiuron, clopyralid, fluroxpyr were detected from the laboratory-analysed water samples, and where ANZECC guideline values were available, generally exceeded the values for 99% protection, but were below the recommended 95% protection levels (Table 10). These herbicides are consistent with agricultural / farming practices and their levels should be monitored in future.

Pesticides / Herbicides in Sediment

No herbicides or pesticides exceeded the laboratory detection levels (see attached ALS laboratory report) in sediment.

Table 10. Pesticides / Herbicides in Water and associated ANZECC guidelines trigger values (ug/L)

	Metolachlor	Atrazine	Simazine	Terbuthylazine	Tebuthiuron	Clopyralid	Fluroxypyr
	(Miscellaneous herbicides)	(Triazine herbicides)		(Herbicide)	(Urea herbicides)	(Herbicide)	(Herbicide)
S1E	0.05	0.21	0.07	0.08	0.03	0.13	0.1
S1M	0.08	0.28	0.12	0.12	0.03	0.15	0.12
S2E	0.08	0.3	0.13	0.12	0.03	0.17	0.1
S2M	0.08	0.31	0.14	0.13	0.04	0.18	0.12
S3E	0.03	0.24	0.02	0.06	0.03	0.17	0.09
S3M	0.04	0.23	0.03	0.07	0.03	0.16	0.08
S4E	0.04	0.22	0.03	0.06	0.03	0.16	0.06
S4M	0.05	0.31	0.03	0.07	0.04	0.19	0.08
S5E	0.03	0.23	0.03	0.06	0.03	0.15	0.08
S5M	0.03	0.22	0.03	0.06	0.03	0.14	0.07
S6E	0.01	0.12	< 0.02	0.04	0.03	0.1	0.05
S6M	0.01	0.11	< 0.02	0.04	0.02	0.13	0.04
ANZECC Trigger Values (ug/L)							
99%	-	0.07	0.2	-	0.02	-	-
95%	-	13	3.2	-	2.2	-	-
90%	-	45	11	-	20	-	-
80%	-	150	35	-	160	-	-

ANZECC Guidelines Trigger Values for water are available in Table 3.4.1 of the guidelines (ANZECC 2000). Grey indicates sites / results that exceed 95% trigger values. Dashed lines represent parameters that do not have trigger values.

4. Conclusion

The results presented here (in particular, the detection of moderate nutrients and herbicides) are consistent with agricultural land-use in the area but for many chemicals there are no reference concentrations in national guidelines to assess health or ecological risks. Furthermore, the detection of an algal bloom during the August sampling event suggests the establishment of an ongoing monitoring program, prior to temperatures increasing (e.g. summer) and flows declining (e.g. during drought conditions), would be a prudent action. Water and sediment quality should be monitored in future to detect longer-term trends to aid in the development of any water / sediment quality management plans for future monitoring and fish death prevention programs.

This report presents a sampling strategy for a rapid assessment of the water- and sediment quality in the Menindee Lakes / Darling River (Menindee) and outlines a sampling plan for water and sediment assessment for future applications. This involves using a combination of in-situ measurements (edge- and middle- sampling using a two water quality meters (Horiba, Sonde)) and water and sediment samples for laboratory analysis (including nutrients in water, BOD, COD, metals, herbicides and pesticides). This sampling plan (methodology) and the results presented here could be used as a rapid assessment tool and as baseline preliminary data and can be applied for future applications to monitor for future fish death events or other environmental disturbances.

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Appendix 1

Table 3.4.2 General framework for applying levels of protection for toxicants to different ecosystem conditions

Ecosystem condition	Level of protection
1 High conservation/ ecological value	• For anthropogenic toxicants, detection at any concentration could be grounds for source investigation and management intervention; for natural toxicants background concentrations should not be exceeded.[a] *Where local biological or chemical data have not yet been gathered*, apply the 99% protection levels (table 3.4.1) as default values. Any relaxation of these objectives should only occur where comprehensive biological effects and monitoring data clearly show that biodiversity would not be altered. • In the case of effluent discharges, Direct Toxicity Assessment (DTA) should also be required on the effluent. • Precautionary approach taken to assessment of post-baseline data through trend analysis or feedback triggers.
2 Slightly to moderately disturbed ecosystems	• Always preferable to use local biological effects data (including DTA) to derive guidelines. *If local biological effects data unavailable*, apply 95% protection levels (table 3.4.1) as default, low-risk trigger values.[b] 99% values are recommended for certain chemicals as noted in table 3.4.1.[c] • Precautionary approach may be required for assessment of post-baseline data through trend analysis or feedback triggers. • In the case of effluent discharges DTA may be required.
3 Highly disturbed ecosystems	• Apply the same guidelines as for slightly–moderately disturbed systems. However, the lower protection levels provided in the Guidelines may be accepted by stakeholders. • DTA could be used as an alternative approach for deriving site-specific guidelines.

a This means that indicator values at background and test sites should be statistically indistinguishable. It is acknowledged that it may not be strictly possible to meet this criterion in every situation.

b For slightly disturbed ecosystems where the management goal is no change in biodiversity, users may prefer to apply a higher protection level.

c 99% values recommended for chemicals that bioaccumulate or for which 95% provides inadequate protection for key test species. Jurisdictions may choose 99% values for some ecosystems that are more towards the slightly disturbed end of the continuum.

Appendix 2

Table 3.3.2 Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by Australian states and territories. Chl *a* = chlorophyll *a*, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NO_x = oxides of nitrogen, NH_4^+ = ammonium, DO = dissolved oxygen.

Ecosystem type	**Chl *a***	**TP**	**FRP**	**TN**	**NO_x**	**NH_4^+**	**DO (% saturation)[l]**		**pH**	
	($\mu g\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	Lower limit	Upper limit	Lower limit	Upper limit
Upland river	na[a]	20[b]	15[g]	250[c]	15[h]	13[i]	90	110	6.5	7.5[m]
Lowland river[d]	5	50	20	500	40[o]	20	85	110	6.5	8.0
Freshwater lakes & Reservoirs	5[e]	10	5	350	10	10	90	110	6.5	8.0[m]
Wetlands	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Estuaries[p]	4[f]	30	5[j]	300	15	15	80	110	7.0	8.5
Marine[p]	1[n]	25[n]	10	120	5[k]	15[k]	90	110	8.0	8.4

na = not applicable;
a = monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers — values for periphyton biomass (mg Chl *a* m^{-2}) to be developed;
b = values are 30 μgL^{-1} for Qld rivers, 10 μgL^{-1} for Vic. alpine streams and 13 μgL^{-1} for Tas. rivers;
c = values are 100 μgL^{-1} for Vic. alpine streams and 480 μgL^{-1} for Tas. rivers;
d = values are 3 μgL^{-1} for Chl *a*, 25 μgL^{-1} for TP and 350 μgL^{-1} for TN for NSW & Vic. east flowing coastal rivers;
e = values are 3 μgL^{-1} for Tas. lakes;
f = value is 5 μgL^{-1} for Qld estuaries;
g = value is 5 μgL^{-1} for Vic. alpine streams and Tas. rivers;
h = value is 190 μgL^{-1} for Tas. rivers;
i = value is 10 μgL^{-1} for Qld. rivers;
j = value is 15 μgL^{-1} for Qld. estuaries;
k = values of 25 μgL^{-1} for NO_x and 20 μgL^{-1} for NH_4^+ for NSW are elevated due to frequent upwelling events;
l = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability (see Section 3.3.3.2);
m = values for NSW upland rivers are 6.5–8.0, for NSW lowland rivers 6.5–8.5, for humic rich Tas. lakes and rivers 4.0-6.5;
n = values are 20 μgL^{-1} for TP for offshore waters and 1.5 μgL^{-1} for Chl *a* for Qld inshore waters;
o = value is 60 μgL^{-1} for Qld rivers;
p = no data available for Tasmanian estuarine and marine waters. A precautionary approach should be adopted when applying default trigger values to these systems.

NON-METALLIC INORGANICS									
Ammonia	D	320	900 [C]	1430 [C]	2300 [A]	500	910	1200	1700
Chlorine	E	0.4	3	6 [A]	13 [A]	ID	ID	ID	ID
Cyanide	F	4	7	11	18	2	4	7	14
Nitrate	J	17	700	3400 [C]	17000 [A]	ID	ID	ID	ID
Hydrogen sulfide	G	0.5	1.0	1.5	2.6	ID	ID	ID	ID

Appendix 3

Page 3.4-5: ANZECC Guidelines Trigger Values

https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf

Table 3.4.1 Trigger values for toxicants at alternative levels of protection. Values in grey shading are the trigger values applying to typical *slightly–moderately disturbed systems*; see table 3.4.2 and Section 3.4.2.4 for guidance on applying these levels to different ecosystem conditions.

Chemical		**Trigger values for freshwater (μgL^{-1})**				**Trigger values for marine water (μgL^{-1})**			
		Level of protection (% species)				**Level of protection (% species)**			
		99%	**95%**	**90%**	**80%**	**99%**	**95%**	**90%**	**80%**
METALS & METALLOIDS									
Aluminium	pH >6.5	27	55	80	150	ID	ID	ID	ID
Aluminium	pH <6.5	ID	ID	ID	ID	ID	ID	ID	ID
Antimony		ID	ID	ID	ID	ID	ID	ID	ID
Arsenic (As III)		1	24	94 [C]	360 [C]	ID	ID	ID	ID
Arsenic (AsV)		0.8	13	42	140 [C]	ID	ID	ID	ID
Beryllium		ID	ID	ID	ID	ID	ID	ID	ID
Bismuth		ID	ID	ID	ID	ID	ID	ID	ID
Boron		90	370 [C]	680 [C]	1300 [C]	ID	ID	ID	ID
Cadmium	H	0.06	0.2	0.4	0.8 [C]	0.7 [B]	5.5 [B, C]	14 [B, C]	36 [B, A]
Chromium (Cr III)	H	ID	ID	ID	ID	7.7	27.4	48.6	90.6
Chromium (CrVI)		0.01	1.0 [C]	6 [A]	40 [A]	0.14	4.4	20 [C]	85 [C]
Cobalt		ID	ID	ID	ID	0.005	1	14	150 [C]
Copper	H	1.0	1.4	1.8 [C]	2.5 [C]	0.3	1.3	3 [C]	8 [A]
Gallium		ID	ID	ID	ID	ID	ID	ID	ID
Iron		ID	ID	ID	ID	ID	ID	ID	ID
Lanthanum		ID	ID	ID	ID	ID	ID	ID	ID
Lead	H	1.0	3.4	5.6	9.4 [C]	2.2	4.4	6.6 [C]	12 [C]
Manganese		1200	1900[C]	2500[C]	3600[C]	ID	ID	ID	ID
Mercury (inorganic)	B	0.06	0.6	1.9 [C]	5.4 [A]	0.1	0.4 [C]	0.7 [C]	1.4 [C]
Mercury (methyl)		ID	ID	ID	ID	ID	ID	ID	ID
Molybdenum		ID	ID	ID	ID	ID	ID	ID	ID
Nickel	H	8	11	13	17 [C]	7	70 [C]	200 [A]	560[A]
Selenium (Total)	B	5	11	18	34	ID	ID	ID	ID
Selenium (SeIV)	B	ID	ID	ID	ID	ID	ID	ID	ID
Silver		0.02	0.05	0.1	0.2 [C]	0.8	1.4	1.8	2.6 [C]
Thallium		ID	ID	ID	ID	ID	ID	ID	ID
Tin (inorganic, SnIV)		ID	ID	ID	ID	ID	ID	ID	ID
Tributyltin (as µg/L Sn)		ID	ID	ID	ID	0.0004	0.006 [C]	0.02 [C]	0.05 [C]
Uranium		ID	ID	ID	ID	ID	ID	ID	ID
Vanadium		ID	ID	ID	ID	50	100	160	280
Zinc	H	2.4	8.0 [C]	15 [C]	31 [C]	7	15 [C]	23 [C]	43 [C]

Appendix 4

Recommended default guideline values for toxicants in sediment

Table 1 Recommended toxicant default guideline values for sediment quality

Type of toxicant	Toxicant	DGV	GV-high
Metals (mg/kg dry weight)[a]	Antimony	2.0	25
	Cadmium	1.5	10
	Chromium	80	370
	Copper	65	270
	Lead	50	220
	Mercury	0.15	1.0
	Nickel	21	52
	Silver	1.0	4.0
	Zinc	200	410

Source: https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

Appendix 4

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Source: https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

Appendix 9

During site visits and within submission, stakeholders raised whether carp numbers could be controlled using a carp virus. Three months prior to the fish death events, the Commonwealth Government released the National Carp Control Plan (NCCP) which investigated the feasibility of the carp virus to control carp numbers, exploring effectiveness, risks and implementation considerations.

National Carp Control Plan & Carp virus

Carp, specifically the common carp (*Cyprinus carpio*), emerged as an environmental problem in Australia in the 1960s. Since that time, there has been significant carp population growth and spread to almost all states and territories. Carp dominates most Murray–Darling Basin (MDB) waterways and can make up approximately 90 per cent of fish biomass in some parts.[1] Although it is classed as a pest in Australia, it is the third most farmed fish globally. Carp density in particular areas can change in times of flood (population growth) and water scarcity, and carp numbers can be highest in lowland rivers.[2]

Negative impacts attributed to carp include reducing native fish populations through mechanisms such as increased resource competition, predation and habitat alteration.[3] The density level at which carp can cause damage has been determined and was used in the National Carp Control Program (NCCP) and is documented in international literature, however this varies depending on the ecosystem and attributes. The NCCP refers to *"50 kg/ha for impacts on fish species, 100 kg/ha for impacts on aquatic plants, and 150 kg/ha for negative impacts on water clarity".*

Social and economic impacts caused by large carp numbers include impacts on tourism and water users due to actual or perceived water quality and impacts on recreational and commercial fishers pursuing other fish species.

Management strategies to date have focussed on finding appropriate methods to reduce the number of and impacts of carp. These have included physical methods such as trapping, angling and mesh screens.[4] While these strategies can go some way to reduce carp numbers, they have not proven to be effective nor sustainable in the long-term. Research has explored using genetics to produce a male-only population (daughterless technology) to limit breeding of carp, which was considered between 1995 and 2012 but never deployed.[5] Research has also explored the use of a targeted virus (Cyprinid herpesvirus 3 / carp virus (CyHV-3)) also known as Koi Herpesvirus Disease (KHV)), to reduce carp populations.[6]

Should carp management strategies be implemented, potential environmental impacts will need to be assessed. This is particularly the case if the carp virus, which has a high disease and mortality rate, is deployed. Traditional Owners, commercial carp fishers, koi carp breeders and enthusiasts and the tourism industry would all be affected in some way whether or not the carp virus is deployed.

What is the carp virus?

It is widely believed that the carp virus was first discovered in Israel in 1998, however it could have been present in the United Kingdom or Germany earlier than this. The carp virus is now widely distributed around the world and is present in over 33 countries, killing millions of carp each year. However, it has

[1] McColl, K. A., and Sunarto, A. (2020). Biocontrol of the Common Carp (*Cyprinus carpio*) in Australia: A Review and Future Directions. *Fishes*, 5(17).
[2] Todd, C. R., Koehn, J. D., Brown, et al. (2019). Modelling Carp Biomass: Estimates for the Year 2023. Arthur Rylah Institute for Environmental Research Unpublished Client Report.
[3] NSW Department of Primary Industries. (n.d.). General Information About Carp.
[4] NSW Industry & Investment. (2010). NSW Control Plan for the Noxious Fish Carp (*Cyprinus carpio*).
[5] Hayes, K. R., Leung, B., Thresher, R., et al. (2014). Meeting the Challenge of Quantitative Risk Assessment for Genetic Control Techniques: A framework and some methods applied to the common carp (*Cyprinus carpio*) in Australia. *Biological Invasions*, 16, 273–1288.
[6] Fisheries Research and Development Corporation, National Carp Control Plan, 2022.

not been *deliberately* deployed as a biological control agent in any country.[7] The virus is not present in Australia nor New Zealand. Introduction has been considered in Australia as part of the NCCP to control carp numbers and minimise their negative impacts. However, in other parts of the world, the virus can have a devastating impact on food resources and related economic output.

The virus (sequence length of 295 kb; double-stranded DNA) is highly specific to carp and koi carp and could reduce carp populations by 40 to 80 per cent.[8] Research from the Commonwealth Scientific Industrial Research Organisation (CSIRO) and globally confirms the carp virus kills carp and only replicates[9] and therefore causes disease, in carp and carp hybrids.[10] There is no evidence that the virus has or can infect humans or other mammals.[11] Although carp virus DNA has been detected in a very small number of animals around the world in the last 30 years (e.g., freshwater fish, a mussel, and a crustacean), there is no evidence the virus replicated in these animals and led to disease.[10] In Australia, research conducted on at least 22 species of fish detected the presence of low levels of viral DNA when they were infected with the carp virus, with none showing signs of the disease and death.[12]

How does the carp virus work?

Direct physical contact between carp is the primary source of transmission of the virus. Some transmission occurs via water and contamination of equipment, however these methods are not particularly effective at infecting the fish as high viral concentrations are required.[8] The virus is temperature dependent. Clinical signs of disease and mortality are observed when water temperatures are between 18 to 28°C. Little or no disease is observed in temperatures outside this range.[13]

When the virus first enters a carp, it targets the carp's gills, skin and kidneys. Disease and mortality rates differ due to water temperature and the overall health status of the carp, but disease can be detected after seven days of infection. Signs include lethargy and loss of appetite, red coloured gills, red mucus on the gills and skin as well as skin tissue death. The disease also inhibits the delivery of oxygen around the fish. Death can occur about a day after the first signs of disease and between 7-21 days post infection, demonstrating a relatively quick reduction of carp populations.[8,14] Carp can become carriers of the virus if they do not succumb to the disease and disease and death from the virus can happen sometime after the initial infection. In this situation, the virus lies dormant within the carp but becomes re-activated at a time when the carp may be under stress conditions, referred to as recrudescence. This is widely acknowledged in literature and was demonstrated when developing the NCCP (see below) as part of a research project (Research Project 4).[11] Researchers in that study confirmed that in juvenile carp in laboratory conditions, disease associated with the virus can become dormant and reactivate at a later time. However, more information is needed about the conditions in which this occurs in nature, what conditions initiate reactivation, how adult carp are affected, how it is activated in different types of carp found in the wild and the time period over which recrudescence can occur. The time period used in the study was two weeks.

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[7] Fisheries Research and Development Corporation. (2022). National Carp Control Plan: Epidemiology and Release Strategies – Technical Paper 2.

[8] Fisheries Research and Development Corporation. (n.d.). National Carp Control Plan – FAQs.

[9] Replication is an essential feature of viral infection. It makes copies of the virus within host cells, enabling them to reproduce and spread to other cells or organisms. This replication is critical for the survival and propagation of the virus.

[10] McColl, K. A., Sunarto, A., and Matthew, N. J. (2018). Biocontrol of Carp: More Than Just a Herpesvirus. *Frontiers in Microbiology*, 9.

[11] Fisheries Research and Development Corporation. (2022). National Carp Control Plan: Carp Virus Species Specificity – Technical Paper 4.

[12] Fabian, M., Baumer, A., and Steinhagen, D. (2013). Do Wild Fish Species Contribute to the Transmission of Koi Herpesvirus to Carp in Hatchery Ponds? The Journal of Fish Diseases, 36 (5), 505-514.

[13] Ronen, A., Perelberg, A., Julia, A., et al. (2003). Efficient Vaccine Against the Virus Causing a Lethal Disease in Cultured *Cyprinus carpio*. *Vaccine*, 21(32), 4677-84.

[14] Adamek, M., Hazerli, D., Marek, M., and et al. (2017). Viral Infections in Common Carp Lead to a Disturbance of Mucin Expression in Mucosal Tissues. Fish and Shellfish Immunology, 71, 353-358.

Response to the virus has been observed. For example, research from laboratory studies suggest that goldfish (a carp hybrid) may be less susceptible to the effects of the carp virus than the common carp.[15] However there is some uncertainty about susceptibility, resistance and tolerance to the virus and disease in carp found in the wild, and particularly in Australian waterways. Nevertheless, it has raised questions and potential plausibility of increasing disease-resistant carp hybrids in circulation post-deployment of the virus, suggesting further research is needed.[16]

National Carp Control Plan

On 1 May 2016, the Commonwealth Government announced it would commit $15.2 million to deliver the NCCP, which was released on 3 November 2022. The NCCP was developed by the Fisheries Research and Development Corporation (FRDC) in collaboration with the Commonwealth Government, State and Territory Governments, research organisations, and other stakeholders. The NCCP investigated the feasibility of the carp virus as a biological control agent while increasing knowledge about virus dynamics, water quality and environmental, social and economic impacts through targeted research projects. Research was led by CSIRO, NSW Department of Primary Industries (DPI) and the Invasive Animals Co-Operative Research Centre.

The NCCP set out to address the following questions:

1. Will biocontrol using the carp virus be effective?
2. What are the risks associated with carp biocontrol and how can they be managed?
3. How could carp biocontrol be implemented?

Below is a summary of the NCCP as they relate to these three objectives.

Will biocontrol using the carp virus be effective?

Research conducted for the NCCP indicates the virus can be highly effective at reducing carp numbers by 40 to 60 per cent, in line with international literature, particularly when (a) water temperatures are optimal for virus replication (18°–28°C) and (b) carp are in close proximity to each other to transmit the virus. These two requirements can occur in spring-early summer when the carp aggregate to spawn.

Additional factors required for effective biocontrol (as described in the NCCP):

- **Integrated reduction strategy:** On its own, the virus is unlikely to reduce the carp population and the use of other methods to reduce numbers would be necessary, particularly in areas with very high carp densities (approximately 2000 kg/ha). This includes removing/harvesting live carp from waterbodies before deployment of the virus and other physical methods. Removing carp prior to deployment can minimise the impact on water quality and other species due to high levels of decomposing carp in the system. This would be most important in the Murray and Darling areas where the highest numbers of carp have been observed.[17] DPI Fisheries has observed increased carp numbers as part of its 2018-2023 sampling in the Lower Darling-Baaka River, and they were observed in high numbers at Menindee following the March 2023 fish death event.[18]
- **Targeted deployment sites:** Deploying the virus in areas where there are large numbers of carp, particularly juvenile carp, can lead to higher mortality rates by facilitating close and controlled direct physical contact between carp.
- **Spring-early summer deployment:** The water temperature in these seasons will be most conducive to replication of the virus within carp once they are infected.

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[15] Fisheries Research and Development Corporation. (2022). National Carp Control Plan: Carp Virus Species Specificity – Technical Paper 4.

[16] McColl, K. A., Sunarto, A., and Holmes, E. C. (2016). Cyprinid Herpesvirus 3 and its Evolutionary Future as a Biological Control Agent for Carp in Australia. *Virology Journal*, 13.

[17] Ivor, S., Fanson, B., Lyon, J., et al. (2019). National Carp Control Plan: Preparing for Cyprinid Herpesvirus 3 – A carp biomass for Australia.

[18] Stocks, J. and Ellis, I. (2023). Native Fish Recovery Strategy: Recovery Reach Program Lower Darling-Baaka Recovery Reach Fish Community Monitoring.

There are some uncertainties around the longer-term suppression of carp populations using the carp virus (Table A9.1**)**, although research to inform the NCCP is ongoing in Australia and internationally to better understand these.

These include:

- **Biomass estimates:** Accurate modelling and predictions about population and distribution of carp across NSW and other states and territories can help predict suppression rates over time. Inputs to this modelling include river flow, water temperature, waterway inundation, and connectivity.
- **Genetic resistance:** Given that carp-Goldfish hybrids may be less susceptible to die from the disease than the common carp, it is uncertain whether they may have a selective advantage, potentially leading to decreased numbers of common carp but increased numbers of carp-Goldfish hybrids over time. Further, investigation into alleles (a variant of a gene that can lead to different traits or characteristics in an organism) within carp that may enable genetic resistance to the virus is needed to exclude the likelihood of genetic resistance based on the genetic makeup of carp populations.
- **Herd immunity:** Carp populations could develop herd immunity to the virus, reducing the mortality rates and effectiveness of the virus.
- **Latency:** *Described above.* If the virus can infect fish and become reactivated at optimal temperatures or under stress conditions, then there is a higher likelihood of reducing carp numbers in the years following virus deployment.
- **Recrudescence:** *Described above.* If this occurs, there are likely to be initial mortalities of carp in the first 1-2 years post deployment, but not in the years beyond.

Table A9.1 What are the risks associated with carp biocontrol and how can they be managed[19]

Impact	What could happen if the virus was deployed (positive)	What could happen if the virus was deployed (negative)	How to minimise the impact if the virus was deployed
Environmental and Ecological			
Water quality	Improved water quality from reduced carp numbers.	• Decaying and decomposing carp can deplete dissolved oxygen, affecting or killing other aquatic organisms. Very high dead carp affect water quality. • Decomposing carp can release of nutrients into the water and sediments and can contribute to algal blooms or are toxic. Bu • The virus could move to non-targeted areas where it can have unintended consequences and where negative water-quality impacts are more likely.	• Deploy the virus when there are low-moderate carp densities (less than 300 kg/ha) • Remove some carp to ensure low-moderate carp densities before deployment. • Ensure carp densities are below approximately 300 kg/ha and the water is flowing. • Deploy the virus in main river channel habitats. • Careful planning and timing of the release of the virus through knowledge about rainfall, flow and carp numbers.
Water treatment	Minimal impact on water treatment processes. *Research conducted for the NCCP identified that the densities of dead carp expected from deployment pose little risk or change to water treatment processes.*	• With very high densities of decomposing carp in the water (2000 kg/ha), water treatment processes and plants would not cope. However, these numbers are unlikely, but could occur in small areas.	• For waterbodies where there were high densities of decomposing carp, water treatment plants can add powdered activated carbon to treat the water. This adds cost but occurs already in NSW to remove algal tastes and blooms. • Management and removal of dead carp prior to deployment to prevent accumulation at high densities in restricted locations.
Bacteria *General decay-specific bacteria, E. coli and various Aeromonas species* *Botulism (caused by bacterial neurotoxins)*		• Decomposing carp in waterbodies can be used as a substrate for bacterial growth that can be harmful to humans and other animals. • As bacterial growth favours temperatures over 20°C, and the ideal temperature range for the virus is approximately 18–28°C, conditions would be conducive for bacterial growth at virus deployment. • Botulism outbreaks are more likely at temperatures over 20°C, therefore it is possible	• See ‘Water quality’.

[19] Fisheries Research and Development Corporation, National Carp Control Plan, 2022.

		to have an outbreak of botulism with release of the virus.	
Virus specificity	Reduced number of carp and carp-hybrids with no impact on non-Carp species. *The carp virus has no infected a human or other mammal.*	• While the literature suggests that the carp virus is highly specific for carp and carp-hybrids, there is a possibility that other fish species can be infected with the virus, but not affected by it. • Increased community concern as there is some concern from the community around the virus potentially affecting fish species other than carp.	• Prior to decision making, further studies would be required to ensure high confidence that the virus will not infect species other than carp, especially native species. Further research should include testing on Rainbow Trout. • Consultation with the community around the results of and outcomes of virus specificity testing to ensure they are confident no other species will be affected. *"Absolute guarantees about the species specificity of any virus, including the carp virus, are not possible, so uncertainty in this area will never be completely eliminated."*
Widespread geographic spread of virus and fish kills		• The carp virus and infected fish move through connected waterways, leading to fish kills in non-targeted areas or states or territories that may not wish to implement the virus. *The NCCP discussed this point and stated that major widespread carp kills occurring is not likely, partially due to the need for targeted direct physical contact in water with temperatures that are optimal for viral replication.*	• Careful planning of location and timeframe of deployment and ongoing monitoring and management. • Deployment when carp are aggregated. • Integration of physical barriers to prevent infected carp migrating to non-targeted areas.
Reduced food availability for native species		• Some native species that rely on carp as a food source may need to find another, if carp numbers are and remain low, or there are food shortages. Research under the NCCP suggests waterbirds may be most affected.	• Regarding waterbirds, plan virus deployment to avoid waterbird nesting periods. • Hatchery rearing and release programs could act as a supplement with decreased carp numbers.
Native species becoming a food source		• Some species may select another food source, such as a native species, as its primary food resource instead, decreasing numbers.	• Hatchery rearing and release programs could act as a food supplement when carp numbers are decreased.
Ephemeral or dryland river systems		• These systems (that dry completely or shrink to small pools when rain fall is low) already have poor water quality. Decomposing carp can exacerbate already poor conditions in these areas.	• Careful planning to avoid negative consequences to ephemeral or dryland river systems.

Ramsar Wetland Systems		• A number of wetlands could be impacted by decomposing carp, which are protected by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the Ramsar Convention.	• Careful planning required to minimise impacts and adhere to EPBC requirements.
Socio-economic			
Traditional Owners	• Empowerment if Traditional Owners were involved in planning, decision making, and implementation. • Improved health of the ecosystem and country. • Improved cultural activities or sites. • Employment opportunities (e.g., harvesting of carp pre and post deployment).	• Disempowerment through lack of engagement in planning, decision making, and implementation. • Health of country affected if deployment led to harmful unintended consequences. • Cultural activities or sites affected if deployment led to harmful unintended consequences.	• Develop an engagement and communications strategy and implement it which consults Traditional Owners at the community and nation level.
Tourism	Sector increases due to increased visits, nature-based tourism and house-boat users as water quality and ecosystem improves.	• Large numbers of decomposing carp can affect water quality and could lead to actual (or perceived) declining water quality.	• See above "Water quality". • Communications plan to inform about potential impacts and likelihood of impacts to water quality from decomposing carp.
Commercial carp fishers	Provide employment opportunities: • live harvesting of carp pre-virus deployment • transition to new business models e.g., turning carp into fertilizer.	• Loss of profit and/or business and market access due to decreased carp numbers. • Increased costs if required to adhere to regulations. • Poor reputation due to actual or perceived presence of the virus. • Poor mental health outcomes from uncertainty and loss of business.	• Consult and communicate on timelines. • Support demand in alternative markets. • Provide guidance about regulatory requirements and provide support to fishers if they have to adhere to requirements due to the circulation of virus. • Support participation in live harvesting. • Provide support for transitioning of businesses.
Native fish aquaculture businesses	Increased business opportunities if native fish restocking occurs alongside carp reduction.	• Loss of profit and/or business and market access if carp deaths negatively impact native fish and reputation. • Increased costs if required to adhere to regulations. • Poor mental health outcomes from uncertainty and loss of business.	

Koi hobbyists and businesses	N/A	• Loss of profit and/or business and market access. • Poor reputation due to actual or perceived presence of the virus. • Increased costs if required to adhere to regulations.	• Consult and communicate on timelines. • Improve biosecurity protocols to reduce the risks on the koi sector. • Provide guidance about regulatory requirements and provide support for adhering to requirements due to the circulation of virus. • Provide support for transitioning of businesses.
Recreational fishers	• Enhanced satisfaction of being near rivers if water quality and the health of the ecosystem improves. • Increased number of native species to fish. • Opportunities for harvesting of fish before deployment and as an ongoing reduction method (e.g., fishing events/competitions) • Increased revenue if carp reduction increases recreational fishing.	• Reduced carp numbers and opportunities to fish for carp. • Reduced social interaction for those that specifically target carp.	• Support participation in live harvesting pre-deployment of the virus. • See 'Water quality'.
Other recreational users	• Enhanced satisfaction of being near rivers if water quality and the health of the ecosystem improves.	• Short-term reduction in amenity and closure of some areas if there are high volumes of dead fish or poor water quality.	• See 'Water quality'. • Deploy the virus in main river channel habitats. • Consult and communicate on timelines.
Communities experiencing large carp numbers	• Reduced carp numbers. • Improved water quality and health of ecosystem. • Increased amenity.	• Large numbers of decomposing carp can affect water quality and could lead to actual (or perceived) declining water quality.	

How could carp biocontrol be implemented?

The NCCP outlines four objectives for virus implementation nationally and notes that states and territories would have their own objectives and requirements to consider. These objectives are:

- Widescale reduction and suppression of carp populations for the medium to long term (5–10 years)
- Effective environmental risk management with no unacceptable impacts on Matters of National Environmental Significance (MNES) under the EPBC Act
- Management of water-quality risks for town water supply, stock and domestic water needs, irrigation, and cultural and recreational purposes
- Effective and efficient virus deployment and carcass management, where the latter is required.

The NCCP suggested a 10-year timeframe for virus implementation, with work primarily targeted in the first four years, and listed four phases of implementation that includes specific activities or strategies related to these.

Planning

Legislative approvals at a national and state level would be required. Nationally, these include the EPBC Act, legislation administered by the *Australian Pesticides and Veterinary Medicines Authority*, the *Biosecurity Act 2015* (Cwth) and the *Biological Control Act 1984*. NSW-specific legislation would include the *Biosecurity Act 2015 (NSW).*

Other actions include:

- Conduct a strategic assessment under the EPBC Act with planning, risk assessment and drafting of statutory documents, and public consultation.
- Determine Catchment Control Areas (CCAs) for virus deployment.
- Develop implementation plans outlining *"operational approaches, requirements and constraints including regional central command and forward command locations".*
- Establish operational coordination.

Operations

- Prepare the virus.
- Establish implementation teams.
- Prepare operations.
- Communications and engagement.
- Deployment
  - Methods:
    - Spring: capture, inject with the virus, and release into the waterway to join the targeted and aggregated sub-population.
    - Winter: capture, inject with the virus, and release into the waterway to join the targeted and aggregated sub-population and wait for a latent infection to be initiated when water temperatures are optimal.
  - Conditions for effective carp knockdown:
    - ensuring this occurs at the optimal temperature range.
    - recrudescence of latent infections is observed.
    - carp aggregate to facilitate direct physical contact and virus transmission.
    - there is a proportion of infected carp within a sub-population.
- Response
  - Carcass management to mitigate environmental risks and adherence to the MNES, manage water quality risks (town water supply, stock, domestic, irrigation and cultural and recreational purposes)

- Carcass management strategies include:
    - physically remove or distribute (via flow and quantity of water) live carp prior to virus deployment
    - using physical infrastructure to restrict movement of carp in some area
    - using water flows to move decomposing carp from a location and infrastructure to block decomposing carp from entering a location
    - use infrastructure to contain decomposing carp in an area where risk to water quality is low.
  - The NCCP recommended methods that do not require manual collection be prioritised where possible, such as wind and water flows, to reduce resource burden.
  - A key component of the response to the virus deployment strategy is what to do with the carp, when harvested before deployment (live) and following virus deployment (dead). The NCCP highlights two commercial opportunities: turning the carp into fertilizer, which is already occurring (e.g., Charlie Carp based in Deniliquin) and for human consumption in Australia and overseas. However, carp do not create significant market opportunities (NCCP).
- Maintenance and learning.

Completion

- Surveillance.
- Monitoring.
- Research.

Costs associated with virus deployment

The NCCP investigated the costs of managing carp via the carp virus. It stated that "*costs and benefits of carp biocontrol are difficult to assess accurately because carp:*

- *inhabit a diverse range of Australian aquatic ecosystems,*
- *vary markedly in abundance among different habitats, and within a given habitat through time, and*
- *cause habitat-specific ecological impacts that interact with a range of other, non-carp stressors."*

The NCCP conducted case studies in discrete locations to obtain an estimate of the costs of deployment. One case study, focussing on the southern Murray and Murrumbidgee systems, found that for a three-year program, virus deployment could cost $190 million in that area (2019 costing). As described earlier and mentioned throughout the NCCP, the physical removal of carp before deployment (particularly in highly populated areas) can better support reducing in carp populations when combined with virus deployment, rather than only deploying the virus. Physical removal of carp can be resource intensive and has associated costs, however these costs were not part of the NCCP's cost analysis and are excluded from the $190 estimate and other estimates in the NCCP. The estimated cost of deployment in the mid-Murray area was approximately $14 million (2019 costing).

Key assumptions related to those costings are (as listed in the NCCP):

- one year for implementation planning and coordination at the regional level,
- two years of initial deployment,
- the second year of initial deployment assumes 60% of year one costings,
- twelve months of community engagement and establishment of regional operations
- platforms,
- six months of operations in each year of deployment, with peak resource application September to December annually,
- deployment in a year with average water levels,

- deployment will target populations where average biomass exceeds 150 kg/ha,
- mortality rate of 60%, and
- clean-up operations targeting identified medium- and high-risk (ecological and socioeconomic) reaches.

Conclusion

Research and work under the NCCP confirm that in Australia, the carp virus could be a biocontrol agent to reduce carp populations initially and for up to ten years. The NCCP concluded that its role in reducing carp populations should be considered further by states and territories.

Biocontrol using the carp virus will not eliminate all carp and should be considered alongside a series of measures to effectively reduce carp populations over time while mitigating ecological impact of decaying carp in the ecosystem, including:

- harvesting carp from over-populated areas prior to virus deployment
- manually removing dead carp from waterways quickly
- implementing water flows and wind conditions to remove dead carp

The NCPP concludes that:

> *Biocontrol using the virus will not eradicate carp, nor will it provide a stand-alone solution for controlling carp in perpetuity. However, successfully implementing carp biocontrol could achieve the following national outcomes and opportunities:*
>
> - *reduced environmental damage caused by carp,*
> - *a 'window of opportunity' during which ecological restoration measures could be implemented to benefit native fish and aquatic habitats while carp impacts are reduced, and*
> - *an opportunity to develop and refine other carp control measures that could then be deployed against carp populations reduced by viral disease.*
>
> *If governments decide to proceed with additional activities to further inform decision making, the next stages will involve additional research, legislative approvals and more detailed planning and risk mitigation."*

Recommendations

The NCCP included 21 recommendations:

Governance
• Establish a national taskforce comprising state, territory, and local government representation to coordinate carp biocontrol implementation. • Obtain Australian Pesticides and Veterinary Medicines Authority approval. • Obtain other mandatory legislative approvals, including those required under the *Biosecurity Act 2015*, the *Biological Control Act 1984*, and relevant state and territory regulatory approvals.
Research

- Undertake additional non-target species susceptibility trials.
- Undertake field-based research aimed at understanding carp population structure and movements to inform epidemiological modelling and operational planning. This research would represent a 'zero-loss' investment, because knowledge of carp population structure would be required for any other future carp control measures, even if governments choose not to proceed with virus release.
- Undertake research on carp virus disease dynamics (particularly seasonal patterns of disease reactivation) under field conditions, or in experimental systems that simulate some of the variability found in nature. This research would enable further assessment of proposed virus release strategies and biocontrol efficacy. Within Australia, research using the virus can only take place in biosecure laboratories, so work of this nature would likely best be conducted internationally, in a location where the virus is already endemic.
- Develop methods for large-scale production, storage, and transport of the carp virus.
- Develop decision-support and mapping tools to support biocontrol operations.
- Assess the animal welfare implications of biological control using the carp virus.
- Clarify the carp virus's capacity to kill carp under saline conditions.
- Further investigate the evolution of resistance to the carp virus, including the potential role of carp-Goldfish hybrids in this evolution.
- Develop and assess ecological risk mitigation options for ephemeral dryland river systems and Ramsar wetlands including the South Australian Lower Lakes system and the associated marine system immediately outside the Murray River mouth.
- Develop and implement pre- and post-deployment monitoring and evaluation plans.

Public Relations

- Develop a comprehensive communications and engagement plan.
- Continue NCCP science communication through the decision-making phase.

Community Consultation

- Publish the NCCP and undertake community consultation.
- Undertake tailored consultation, in addition to that completed under the NCCP, with Traditional Owners.
- Undertake specifically designed consultation with other stakeholder groups identified by the NCCP.

Stakeholder Engagement

- Actively engage Traditional Owners in decision making and enterprise development associated with carp biocontrol.
- Engage local knowledge and stakeholders in regional implementation planning.
- Acknowledge possible stakeholder impacts, including anticipatory impacts.

Appendix 10

Emergency management framework

The NSW Emergency Management arrangements are set out by the NSW State Emergency Management Plan (the EMPLAN)[20], as legislated under the *State Emergency and Rescue Management Act 1989* (SERM Act)[21]. Together, the EMPLAN and SERM Act establish the principle of a lead agency (for example, a 'combat agency' that has responsibility for leading the emergency response, such as NSW Rural Fire Service for bushfires) and the Functional Areas (the Functional Areas that are involved in the planning for, preparation for, responses to or recovery from an emergency).

The EMPLAN is currently being rewritten to also include supporting agencies that support a 'combat agency' during an emergency. It is important to also understand what constitutes an emergency, with the SERM Act defining an 'emergency' as:

> *"An actual or imminent occurrence (such as fire, flood, storm, earthquake, explosion, terrorist act, accident, epidemic or warlike action) which:*
> *a. endangers, or threatens to endanger, the safety or health of persons or animals in the State, or*
> *b. destroys or damages, or threatens to destroy or damage, property in the State, or*
> *c. causes a failure of, or significant disruption to, an essential service or infrastructure*
> *being an emergency which requires a significant and co-ordinated response*."

Specifically, the EMPLAN outlines the command, control and coordination structure, including roles of agencies and coordination, and embeds the following principles:

- adoption of the Comprehensive approach in emergency management of Planning, Preparation, Response and Recovery (PPRR)
  - Prevention: to eliminate or reduce the level of the risk or severity of emergencies
  - Preparation: to enhance capacity of agencies and communities to cope with the consequences of emergencies
  - Response: to ensure the immediate consequences of emergencies to communities are minimised
  - Recovery: measures which support individuals and communities affected by emergencies in the reconstruction of physical infrastructure and restoration of physical, emotional, environmental and economic well-being.
- continuous improvement of responsible agencies (through lessons management)
- coordination and information sharing (including identification and involvement of further stakeholders, including subject matter experts, at the earliest opportunity)
- an 'all-hazards' approach (i.e., standardised systems and methods of operation)
- an 'all-agencies' approach (i.e., in order to respond to an emergency, no one agency can address all the impacts)
- recognition of capability at the local level, with escalating support from the region and state;
- emphasizes community and stakeholder engagement, including in preparing and implementing emergency plans
- disaster resilience and risk planning
- highlights capability and resourcing requirements of the above.

Further detailed information for specific situations is provided by Sub Plans, Supporting Plans and Regional Plans: Sub Plans outline the response to a specific hazard and/or event (such as floods), Supporting Plans outline specific responsibilities of agencies and/or Functional Areas under the

[20] NSW Government (n.d.). State Emergency Management Plan (EMPLAN).
[21] *State Emergency and Rescue Management Act 1989* (No. 165)

EMPLAN, and Regional Plans designate emergency management regions and specific responses that are managed on a regional basis.

Key acronyms and terminology from the State Emergency Management framework that are of importance to this review include:

- Local Emergency Management Committee (LEMC) operates at the local area/government level and gives effect to emergency management policy and coordinate emergency management practice. LEMC's undertake risk and hazard assessments, develop managements plans and assist in the coordination of the response with local agencies, organisations and the community, as well as other agencies and entities (such as the EOC).
- Emergency Operations Centre (EOC) is the central entity during an emergency that leads and coordinates the response, including providing situational awareness (i.e., collection and dissemination of information) and coordination/allocation of resources/assets. The EOC can be Local, Regional or State level in its operation. It is important to note that an EOC can be scalable in an event with not every Functional Area or Supporting Agency present.
- Emergency Operation Controller (EOCON) roles: the State Emergency Operation Controller (SEOCON), the Regional Emergency Operation Controller (REOCON) and the Local Emergency Operation Controller (LEOCON)
    - In the absence of an identified combat agency or where the identified combat agency requests, the responsibility for managing the emergency response falls to the EOCON (SERM Act)
    - EOCON roles are based on the geographical extent of an emergency, and in all instances are dealt with at a local level and then escalated from the local to regional, regional to state.

Sub Plans and Supporting Plans that could be activated and affect fish kill emergency management responsibilities

In relation to this Review, the following sub and supporting plans to the NSW EMPLAN could be activated under a range of fish death scenarios:

- Flood Sub Plan and Storm Sub Plans aim to minimize the impact of floods and storms (respectively) and enhance the response and recovery capabilities of agencies and communities. As per the State Emergency Service Act 1989, the State Emergency Service (SES) will act as the Combat Agency for dealing with floods and storms, and the associated coordination of evacuation and welfare of affected communities.
- Environmental Services Supporting Plan aims to minimize the environmental impact of hazards/risks and protect natural resources. It also aims to ensure the effective management and recovery of the environment during and after incidents, with the EPA as the Combat Agency.
- Far West Regional Emergency Management Plan covers arrangements for supporting emergencies by the Combat Agencies, the REOCON, and the transition from response to recovery in the Far West Region of NSW which encompasses Menindee and the surrounds. The plan contains region-specific profile information, such as boundaries, climate and water information, land use, and population information. It also contains regional planning considerations and risk.
    - Under the Far West Regional Emergency Management Plan, the NSW SES is (as per the Flood Sub Plan and Storm Sub Plan) the responsible agency for flood and storm emergencies in the Central Darling.
- Biosecurity (Animal and Plant) Sub Plan outlines the management of an event which threatens animal, aquatic or plant biosecurity, or invasive species (vertebrate, invertebrate and weed species). It designates the NSW DPI as the Combat Agency.

- New South Wales Health Services Functional Area Supporting Plan (NSW HEALTHPLAN) outlines the coordination of all health service resources for the reacting to a health emergency. NSW Health is the identified Combat Agency for all human health emergencies in NSW and the functional area responsible for providing health support under the EMPLAN (as managed by the State Health Services Functional Area Coordinator, the State HSFAC). Mental health is also covered within the NSW HEALTHPLAN.